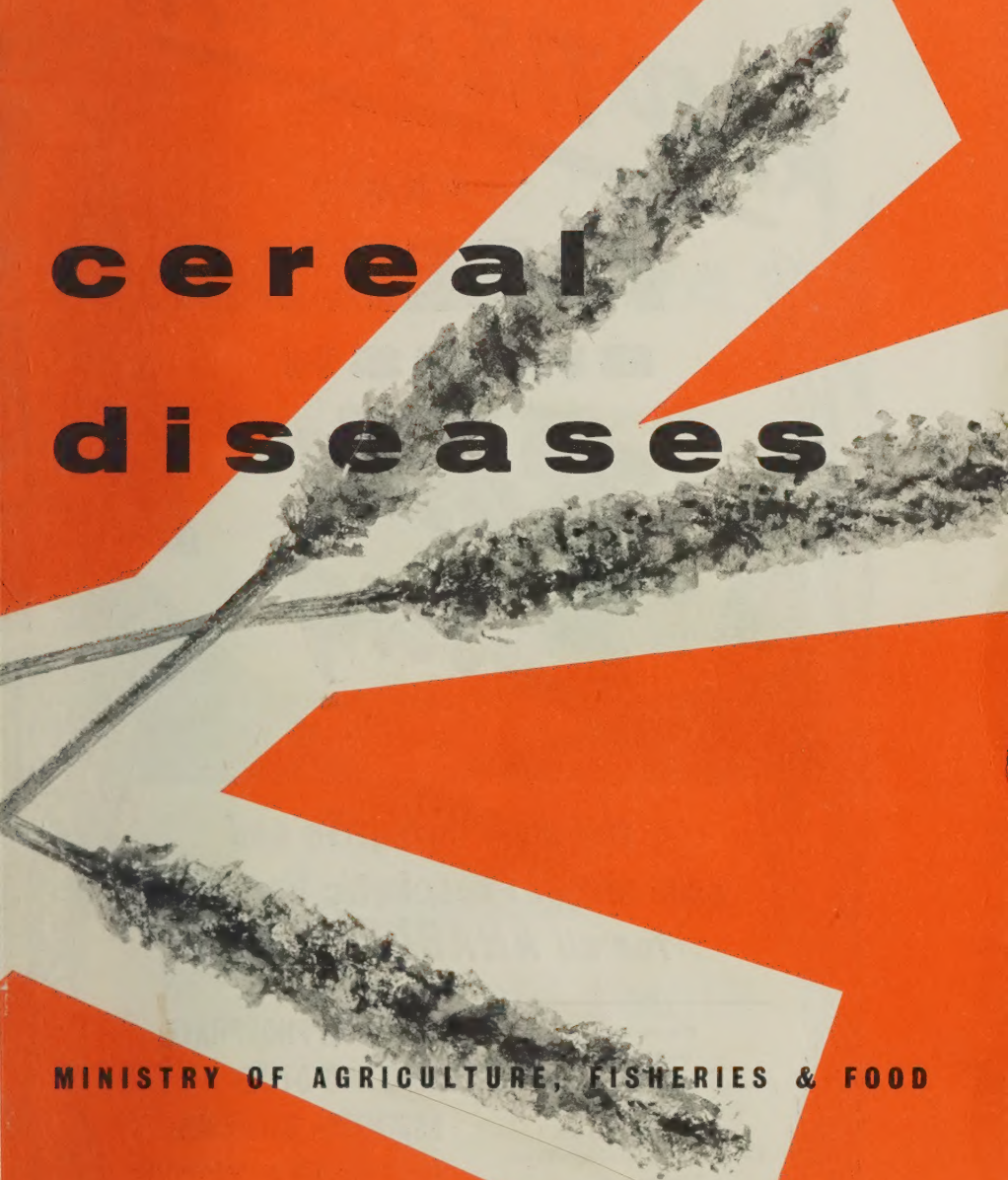
COMPLIMENTARY

BULLETIN NO. 129

cereal diseases



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MINISTRY OF
AGRICULTURE, FISHERIES AND FOOD

Cereal Diseases

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LONDON
HER MAJESTY'S STATIONERY OFFICE
1961

Foreword

THE important place of cereals in the war-time food production programme brought into prominence the problems of failure and loss through disease, which in turn revealed the need for a short general account of the diseases of cereals occurring in Britain. This bulletin was therefore prepared in the hope that it might be a guide and help to all those interested in the cultivation of cereals, whether the farmer himself, the adviser professionally engaged in giving advice on plant diseases, or the student of agriculture. The chief aim has been to provide comparatively simple but accurate descriptions of the many cereal diseases that exist in this country: to indicate, wherever possible, the factors that influence their seasonal prevalence and intensity: and to suggest the measures that should be taken to control or prevent them. The more technical aspects of the subject have, therefore, purposely been avoided or relegated to footnotes. A few diseases of importance abroad, but not yet recognized in Britain, are also included.

By no means all the diseases discussed are of economic significance and, fortunately, none of them causes the catastrophic losses sometimes experienced in other countries. Those that do most damage here are Yellow Rust, Take-all, Eyespot and Mildew. Even these vary considerably in intensity from season to season, and in some years there are others that may be equally important. Considerable confusion is frequently caused—and not only among farmers—by the loose use of the terms "blight", "rust" and "mildew" for diseases of the most diverse origin. It cannot be repeated too often that successful prevention or control depends first and foremost on correct diagnosis, and farmers are urged to seek advice from their County Agricultural Officer of the National Agricultural Advisory Service and, if necessary, through him from the Specialist Plant Pathologist.

Plant Pathology Laboratory
Ministry of Agriculture, Fisheries and Food
September 1961

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Rusts

It is not difficult to distinguish the half-dozen or so cereal rusts from other cereal diseases, because all of them form easily recognized, more or less rust-coloured pustules or stripes on the leaves of affected plants. The variety of spore forms that these fungi produce, however, and the different behaviour and function of each kind of spore, provide a story that is not easy to grasp. Nevertheless, some idea of the behaviour of these fungi is necessary for a proper understanding of rust diseases and their control. The essential details are given below for individual rusts and it is sufficient here to emphasize two general points.

The first is that two host plants are required for the full development of the cereal rusts, though not necessarily for their continued survival. One host is a cereal crop or grass and the other a wild or cultivated herb or shrub. The spores produced by the rust on the herb or shrub can infect only the cereal or grass. On the cereal or grass there are two kinds of spores: (i) the teleutospore, which can infect only the herb or shrub, so that normally there must be a regular alternation between the two hosts to complete the life cycle of the rust, and (ii) the uredospore, which can re-infect the cereal and so spread the rust rapidly through the cereal crop. If, therefore, the uredospores are able to withstand winter conditions, the rust can survive from one season to the next without the intervention of the second host. But if the uredospores are killed during the winter the continued survival of the rust must, as a rule, depend on the presence of the other host. The point can be illustrated by reference to Black Stem Rust which lives on wheat and barberry and the Brown Rust which lives on wheat and meadow rue (*Thalictrum*). The uredospores of Black Stem Rust are usually killed during the winter in Britain, and the survival of the rust is therefore dependent on the fungus returning to wheat from the barberry unless, as more often happens, uredospores are carried by wind from continental areas. The uredospores of Brown Rust, on the other hand, are not killed by winter conditions in Britain, and thus they are able to begin the attack on the new wheat crop, without the intervention of the *Thalictrum*.

The second point is equally, perhaps more, important. It is that cereal rusts are very specialized in their attacks. For instance, although it is not possible to distinguish the Black Stem Rust on wheat from Black Stem Rust on oats, barley, or rye, even under the microscope, the fungus from wheat is not always able to attack barley or oats or rye, and vice versa. Indeed, the rust on one variety of wheat will often not pass over to other varieties of wheat. In other words, there are a number of different strains of each cereal rust. These strains are called physiologic races, and each one of them may be restricted in its attacks to a single cereal host (e.g., wheat), to a few varieties, or even to a single variety of wheat, oats or barley. Moreover, the physiologic races of a rust occurring in one district may differ from those in another district of the same country, and the races occurring in one country may differ from those in another country. The practical importance of this more or less rigid specialization lies in the difficulties it presents to the plant

breeder who is endeavouring to raise rust-resistant or immune varieties—the most effective way of dealing with the problem of cereal rusts. A new variety of wheat, bred for resistance to Yellow Rust, cannot be accepted as resistant in all parts of a country unless it has been tested and proved resistant to all the physiologic races of Yellow Rust known to occur in that country. Even then it is always liable to become attacked if a new strain of the rust appears. Similarly, a variety of proved resistance in Canada or Australia may be attacked in Britain, where different physiologic races are almost certain to exist.

BLACK STEM RUST

Black Stem Rust attacks wheat, oats, barley and rye, and various grasses, but does most damage to wheat. It is caused by a fungus named *Puccinia graminis* Pers. which lives part of its life on wheat and part on the common barberry, *Berberis vulgaris*. The fungus, usually called Stem Rust or Red Rust in the New World, occurs wherever cereals are grown; it takes a regular annual toll in parts of North America, Australia, South Africa and Europe, and has caused devastating losses in years favourable to rusts, such as 1904 and 1916 in North America. In Britain it is seen nearly every year on wheat in the south-west, and slight attacks are found some years in a few other districts, but as a rule the rust develops late and does little damage. Now and again, as in 1924, 1940 and 1955 it becomes epidemic in August in many parts of England and Wales, and may then reduce yields, but on the whole Black Stem Rust has little economic significance here. Oats are not infrequently attacked but the rust is rare on barley and rye. It is sporadic on oats in Scotland and at times damaging in south-eastern districts where barberry bushes are common.

In spring *Puccinia graminis* may be found on the under-surface of barberry leaves in the form of yellow or orange-coloured patches, up to $\frac{1}{2}$ in. across, composed of numerous closed cluster cups tightly packed together. A few weeks later the cluster cups open, and the numerous spores (aecidiospores) they contain are exposed as a yellow powder that is readily carried about by wind. These spores are unable to attack the barberry again, but if blown to wheat plants they infect them and soon give rise to the summer or red rust stage, visible as reddish-brown lines or spots on the leaves and stems. These lines and spots contain masses of summer spores (uredospores) which, when blown about, serve to spread the disease among the crop and from it to other wheat crops. The red rust stage is later succeeded by a black stage, recognizable by the presence of conspicuous black streaks on the leaf sheaths and stems. The black colour is due to the production of spores of a third type—the teleutospores or resting spores—which remain dormant during the winter on the straw and stubble. When the teleutospores germinate in spring the spores (sporidia) which they produce cannot infect wheat or other cereals, but may return to the barberry and reproduce the cluster-cup stage.

As the uredospore is the only form of spore able to pass direct from one wheat plant to another it follows that, unless the uredospores remain alive over winter, perhaps on volunteer plants, or are transported from areas where they can survive, the barberry is essential for the continued existence of Black Stem Rust. That they do live between the seasons in some warm countries is clear, for Black Stem Rust is often severe in Australia, where the barberry is rare and not usually naturally affected. But in Britain they are

relatively short-lived and are generally killed by winter temperatures, so that the source of the rust most years is uredospores carried over by wind from the Continent or, very occasionally, affected barberries. Once the disease has appeared on wheat plants, however, the uredospores formed on them may be blown many miles by wind to infect crops far removed from barberry bushes. It is known that many species of *Berberis* (other than *B. vulgaris*) and *Mahonia* can be infected artificially with *Puccinia graminis*, and on rare occasions the fungus has been found occurring naturally in Britain on *Mahonia aquifolium*[1] and two or three closely allied species, but no garden species of *Berberis* other than *B. vulgaris* is of practical significance as far as the spread of Black Stem Rust is concerned. There is little or no risk of the rust being transmitted with seed wheat. It is true that uredospores and teleutospores may occasionally be present on the grain, but most of the uredospores die between harvest time and sowing, and the teleutospores cannot infect cereals. For the same reason it is unlikely to be carried back to wheat with infected straw litter returned to the land in manure.

One other point deserves emphasis. Although Black Stem Rust on wheat cannot be distinguished microscopically from Black Stem Rust on barley, oats, rye, or grasses, a great many physiologic races of the fungus are known. Some of these are restricted in their attack to one or two hosts and some to one or a group of varieties of the same host. For instance, wheat varieties resistant to some races fall victims to others, and this seriously complicates the work of the plant breeder in raising resistant or immune varieties. In general, spring sown wheat is attacked more severely than autumn sown, especially in years when the spring sown matures late, and early maturing varieties suffer least because the straw is often nearly ripe before the rust appears. In North America it has been shown that certain rust resistant varieties of wheat, in the presence of Black Stem Rust, develop brown, dark brown, or blackish blotches on the stems, leaf sheaths, and glumes. These blotches ("Brown Necrosis") resemble and may be mistaken for the symptoms of Black Chaff (see p. 32).

The chief measures for dealing with Black Stem Rust are voluntary or compulsory eradication of barberries and selection and breeding of resistant or immune varieties. Experiments carried out abroad have shown that the rust can be controlled effectively by frequent applications of sulphur dust at the rate of about 30 lb per acre, and this method is suitable for seed growers and grain exhibitors where epidemics may be expected, but it is impractical on a large scale and in Britain the disease is rarely of sufficient severity to warrant special treatment.

YELLOW RUST

In England and Wales the Yellow Rust fungus, *Puccinia striiformis* Westend., does more harm than either of the other rusts on wheat; in Scotland it is seldom serious. It is not uncommon on barley and has been seen occasionally on rye, as well as on certain grasses such as cocksfoot and couch, but does not attack oats. The rust is most prominent on the foliage, appearing as lemon-yellow pustules that are almost always arranged in parallel lines along the leaves, and may also occur on the stems and ears. When severely affected

[1] A different rust, *Puccinia mirabilissima* Peck, is widely distributed on *Mahonia aquifolium* in Great Britain; but it has nothing to do with the rust on cereal crops.

the leaves wither and die prematurely; as a result, less food material is produced and much of the grain remains small or is shrivelled. The pustules contain two kinds of spores; yellow summer spores (uredospores), which spread the rust among the crop and from one wheat crop to another, and black resting spores (teleutospores). When the teleutospores germinate they produce another kind of spore (sporidia), but these do not infect cereals. It is possible that, like those of Black Stem Rust, they may infect some entirely different host, but if so the host is unknown and deliberate attempts to infect *Berberis vulgaris*, *Mahonia aquifolium* and certain other plants have failed.

The survival of Yellow Rust is therefore dependent on the uredospores which, though often killed by high summer temperatures, are able to withstand many degrees of frost. In autumn the rust lives for a time on green tillers among the stubble and on self-sown plants, and later passes over to autumn sown crops. Occasionally spore pustules develop on the foliage in January but most years the fungus lies dormant within the plants for some weeks and does not become really noticeable until May. The degree of attack depends largely on weather conditions. Mild winters promote a fairly lush growth, uredospores survive in quantity, and the attack may be early and heavy. Nevertheless, crops severely rusted in early spring sometimes grow away from the rust later, especially during warm periods. On the other hand, the disease is usually scarce after very hard winters or unusually hot summers. Soil and manurial conditions are also important. There is usually more rust on crops in deep loam and heavy soils than in light soils or shallow soils over chalk. High nitrogen favours rusting, and liberal applications of potash render the plants more resistant.

Varieties of wheat differ widely in their liability to attack. At least eight physiologic races have been recognized on wheat in Britain and one of these is distinct from any recorded elsewhere. Most of the varieties now commonly grown are moderately or highly resistant to some races but nearly all are susceptible to attack by at least one of the races occurring in this country. Plants attacked by Bunt are more susceptible to Yellow Rust than healthy plants of the same variety.

Judicious selection of varieties is the best method of dealing with Yellow Rust. In districts and soils where the disease is troublesome it may be advisable to grow one of the more resistant varieties. It must be borne in mind, however, that only about once in ten years is Yellow Rust sufficiently bad to reduce yield appreciably. Seed treatment has no effect but on small trial plots the disease can be kept in check by several applications of sulphur dust (30 lb per acre).

BROWN RUST OF WHEAT

The third rust fungus on wheat, *Puccinia triticina* Erikss., is common but relatively harmless in England and Wales, and widespread in Scotland. It does not attack other cereals. It develops later than Yellow Rust but earlier than Black Stem Rust, and usually becomes abundant on the foliage in July and August as scattered brown pustules similar to, but rather lighter in colour and smaller than, those of Black Stem Rust. Few resting spores (teleutospores) are found in Britain. Brown Rust, like Black Stem Rust, lives on two hosts, for in the United States of America and Russia the sporidia formed when the teleutospores germinate have been shown to produce a cluster cup stage

(with aecidiospores) on several species of *Thalictrum*. In this country no species of *Thalictrum* has yet been found naturally infected by it. The uredospores survive in late autumn and winter on self-sown plants, and from these pass to autumn-sown wheat, though when temperatures are low there may be a long period between infection and the formation of fresh uredospore pustules. Varieties differ widely in their susceptibility, but the degree of attack on individual varieties depends partly on external conditions; low light intensity and low temperatures appear to increase resistance. On the other hand, resistant varieties may lose much of their resistance when attacked by Mildew (*Erysiphe graminis* DC.). Ten physiologic races of *Puccinia triticina* have been recognized in England and Wales, and eight of these differ markedly from the many forms found in Europe and North America.

BROWN RUST OF BARLEY

The commonest rust on barley is *Puccinia hordei* Otth,[1] which causes little or no significant damage. It produces numerous, very small and scattered, orange-brown uredospore pustules on the leaves in May and June, and in late summer a crop of teleutospores. The alternate host is *Ornithogalum umbellatum*, but the aecidial stage has been seen only once in Britain (1948) and the fungus probably survives the winter here in the uredospore stage. Like many other rusts, it exists in a number of physiologic races, four or five of which have been distinguished in England.

CROWN RUST OF OATS

This rust, named *Puccinia coronata* Corda, is common and widely distributed throughout Britain. It is most prevalent in Wales and south-west England, and heavy attacks occur sometimes in southern and northern districts, but it is generally slight in the east. Normally the rust develops fairly late and does little harm; in some years, however, the foliage is golden yellow with it in June or July, especially in western districts, and when this happens yields may be poor and the ears indifferently filled. Crown Rust does not attack other cereal crops but occurs on a number of grasses, including rye-grass (*Lolium perenne*) and meadow foxtail (*Alopecurus pratensis*). Two kinds of spores develop on oats; uredospores, which are produced in pinkish or orange pustules on both sides of the leaves, and teleutospores, which form black pustules on the leaves and sheaths. The uredospores spread the rust from one oat crop to another and tide over from one season to the next on volunteer or autumn sown oats. The teleutospores germinate in spring to give other spores (sporidia) which cannot infect oats but pass to buckthorn (*Rhamnus cathartica*) on which a cluster-cup stage with aecidiospores is soon formed. In districts where the buckthorn grows, the cluster-cup stage is not uncommon, and as the aecidiospores re-infect oats, these spores may contribute materially to the attack on oat crops in the vicinity, though the buckthorn is not necessary for the survival of the fungus. In Wales overwintering on autumn-sown crops and volunteer plants appears to be the main source of infection. At least thirteen physiologic races of Crown Rust have been distinguished on oats and grasses in Britain. Some infect only one and some several kinds of grass, but it is rare for the races on grasses to attack oats, so

[1] Sometimes called *Puccinia simplex* (Körn.) Erikss. & Henn., or *P. anomala* Rostr.

that infected grasses are seldom likely to be a source of danger to neighbouring oats. Not all the races on grasses form their cluster-cup stage on buckthorn; some produce it on the closely related *Frangula alnus*[1] or, in other countries, on other species of *Rhamnus*.

Crown Rust can be effectively controlled by dusting with sulphur at the rate of 30 lb per acre, but only by weekly applications in July and August. In this country the treatment is neither necessary nor practical except perhaps on trial plots or for special purposes.

BROWN RUST OF RYE

The Brown Rust of rye closely resembles Brown Rust of wheat and is a common but unimportant fungus in districts where rye is grown; it does not attack any other cereal. Its name is *Puccinia dispersa* Erikss. & Henn. em. Erikss.[2] and it produces both uredospores and teleutospores. The uredospores live through the winter and the teleutospores, which often germinate in autumn as soon as they are ripe, give rise to sporidia which produce a cluster-cup stage on species of *Anchusa*. This cluster-cup stage has been seen on rare occasions on *Anchusa arvensis* in England and Scotland.

MAIZE RUST

Maize is attacked by a Rust named *Puccinia sorghi* Schw., which lives part of its life on species of *Oxalis*. It is common in those countries where maize is widely cultivated and has been reported in late autumn on several occasions in England.

Smuts

THERE are a number of cereal smuts and all of them are parasitic fungi which can easily be recognized by the black, soot-like masses of spores they form. One or two of them produce these spores on all the overground parts of the plants they attack, but as a rule it is only in the ears and grain that the spores develop. Two broad classes of smut — covered and loose — can be distinguished. In covered smuts the spore masses remain enclosed for a time within the skin of the grain and may not become visible externally until the crop is ripe or until after it has been harvested. In loose smuts the black spore masses become apparent as soon as the affected ears emerge from the sheath; moreover, the spores are soon exposed and blown away, so that before long little or nothing may be left of the smutted ear but a bare stalk. In general, cereal smuts are specialized to their hosts; that is, a smut which attacks one cereal is unable to infect any other cereal. Sometimes the relation

[1] At one time the name *Puccinia coronata* Kleb. was restricted to the Crown Rust occurring on grasses and *Frangula alnus*, while Crown Rust on oats, certain grasses and *R. cathartica* was called *Puccinia coronifera* Kleb. or *P. lolii* Niels. It is now considered preferable to use the name *P. coronata* Corda for all forms of Crown Rust on oats and grasses.

[2] Also called *Puccinia secalina* Grove.

between host and parasite is even closer for, as in cereal rusts, there are physiologic races of smuts which are confined to individual varieties of one cereal host. One other broad distinction requires emphasis here because it has an important bearing on smut control. Some smuts (usually the covered ones) infect the germinating grain, and these can be prevented by treating the seed with a fungicide before it is sown. Others (usually the loose smuts) infect their hosts through the open flowers and cannot be controlled in the same way.

BUNT OF WHEAT

For several years after the 1914–18 war, and probably because of the shortage of good seed stocks, it was by no means uncommon in England and Wales to find 20–50 per cent of the ears in a wheat crop bunted, and as many as a third of the wheat samples sent to the Official Seed Testing Station at Cambridge for examination were affected. In recent years such bad attacks have been few and far between and less than 1 per cent of the samples tested at Cambridge have been bunted. In Scotland the disease has long been rare. Bunt has been found very occasionally on rye in England but oats and barley are not attacked. The name of the bunt fungus is *Tilletia caries* (DC.) Tul.[1]

Plants infected with Bunt cannot be recognized with certainty until the ears emerge and then only by an experienced eye. Bunted ears are narrower and rather longer than healthy ones and have a bluish tinge; but as they ripen the chaffy scales become pushed apart because the affected grains enclosed by them are plumper and shorter than normal ones (Fig. 1). As a rule all the ears of an affected plant and all the grains in an affected ear are bunted. Bunted grains, sometimes called "butts" (Fig. 2), are brownish and consist of a black mass of more or less greasy spores which smell fishy; hence the old name Stinking Smut. Some of these grains burst and reveal their black contents before harvest, but usually they remain intact and are harvested and threshed with the healthy ones. During threshing most of the bunted grains burst open (Fig. 3) and the millions of spores they contain are scattered. Many adhere to the surface of the healthy grains and may even blacken it, especially at the brush end. It is thus spoiled for milling purposes and rendered harmful for use as seed unless suitably disinfected, but reasonable quantities of such grain can be fed to cattle, pigs and poultry without any appreciable ill effects. Other spores remain in the threshing machine and serve to contaminate the next lot of wheat threshed in it. The sacks or containers into which bunted grain is put will also become contaminated and if subsequently used to hold clean grain will contaminate this also.

When grain bearing bunt spores is sown, the spores and the grain germinate more or less together and the fungus enters and infects the young wheat sprout before it is half an inch or so long. Once the fungus is inside the young seedling its mycelium keeps pace with the growing seedling but does not materially affect the health or appearance of the plant. When the ear is formed and the grain is developing, however, the fungus begins to

[1] A closely related species, *Tilletia laevis* Kühn, is a common cause of Bunt in North America and sometimes elsewhere, but there is no authentic record of this species occurring in growing crops in Britain; it has been seen once (1929) on "chicken corn" believed to have been imported. Another species *T. contraversa* Kühn causing Dwarf Bunt occurs in North America and several countries in Europe; it has not been seen in Britain.

produce its black spores inside the grain and gives rise to typical bunted ears. Infection occurs underground and only when the grain germinates; Bunt does not spread from plant to plant in the crop. In some countries infection appears to occur at times from spores left in the soil, but in Britain there seems to be little risk of the disease developing in wheat following a bunted wheat crop provided the seed is clean or has been disinfected. Fairly low soil temperatures favour infection and winter sown wheat is usually attacked more severely than spring sown. Lists of resistant and susceptible varieties have been drawn up from time to time, but they are of no great value, for the bunt fungus exists in a number of physiologic races, each restricted to its own variety or group of varieties, so that apparent resistance or susceptibility in a variety may depend, for instance, on the presence or absence of a particular physiologic race in the district where the variety is tested.

Bunt can be prevented by disinfecting the seed before sowing. Organo-mercury dusts or liquid formulations provide a safe and very effective way of doing this and seed disinfection with one of these materials should be regarded as an essential routine practice wherever cereals are sown. Where they are to be grown on land where wireworms are likely to be troublesome seed treatment with an organo-mercury fungicide combined with a BHC (benzene hexachloride) insecticide can be used.

At one time many growers dipped their seed wheat for 5 minutes in, or sprinkled it with, a solution of copper sulphate (bluestone) made by dissolving 2½ lb of copper sulphate in 10 gallons of water. Copper sulphate frequently injures the grain, however, and in the early twenties of this century it was largely superseded by another sprinkling method, using a solution made by mixing 1 pint of 40 per cent formaldehyde with 40 gallons of water. Provided care is taken, formaldehyde does not adversely affect germination but both of these "wet" methods are slow and laborious, and both must for safety's sake be carried out within 48 hours of sowing. Efforts were therefore made to devise suitable treatments with dry powders, and copper carbonate dust, used at the rate of 2 oz per bushel of wheat, proved to be effective and became widely used in Australia, North America and elsewhere, though it failed to find favour in Britain. After 1940 all these methods were displaced by dry dusting with organo-mercury compounds. The mercury dusts are safe and efficient if properly used; moreover, they are effective against certain other seedborne cereal diseases which cannot be controlled by treatment with bluestone, formaldehyde or copper carbonate, and they help to reduce damage in storage by rats and other vermin.

There are a number of proprietary organo-mercury fungicides and combined insecticide-fungicide materials, both in dust and liquid formulations, on the market. Most of them have been approved under the Agricultural Chemicals Approval Scheme[1] of the Ministry of Agriculture, Fisheries and Food and Department of Agriculture and Fisheries for Scotland for the control of Bunt and certain other seed borne diseases of cereals. Many merchants are now prepared to supply seed already treated. The rate of application for the dusts is normally 2–4 oz per cwt and for the liquids ¾–2 fl. oz depending on the chemical and the seed to be treated. Precise instructions on usage are given on the labels and these should always be followed very carefully.

[1] A list of products approved under this scheme may be obtained on application to the Ministry of Agriculture, Fisheries and Food (Publications), Ruskin Avenue, Kew, Richmond, Surrey.

For treating grain with dusts a range of machinery is available from small churn-types for use by farmers to large power-driven automatic machines for merchants dealing with large quantities of grain. Organo-mercury compounds can, in certain circumstances, be injurious and anyone handling the dusts or treated grain is strongly advised to wear rubber gloves and an effective dust mask. For application of the liquid formulations special machines are necessary. The mercury compounds in some of these formulations are considerably more dangerous than those in the dusts and the materials are only supplied to establishments covered by the Factory Acts, 1937–59.

Well conditioned grain kept under good conditions of storage is rarely damaged by these treatments when they are correctly applied. If excessive doses are given or if the grain is damp when treated or kept under damp conditions after treatment and before sowing there is a risk of injury. Under such conditions the seed may be killed outright or if germination takes place the young shoot becomes abnormally thickened almost at once, the roots thickened and stunted and growth ceases. These symptoms develop most markedly in wheat, less so in oats, least of all on barley. Treated grain should not be used for human or animal consumption.

LOOSE SMUT OF WHEAT

Loose Smut of wheat, though widely distributed throughout Britain, is of relatively minor importance here, and this is fortunate because it is very troublesome to control. It is caused by the fungus *Ustilago nuda* (Jens.) Rostr. and it will also attack rye, though it has not been found on rye in Britain. A few affected ears, rarely amounting in all to more than 1 per cent, can be found every year in many wheat crops, but occasionally severe attacks with 15 per cent or more of smutted ears are seen.

Loose Smut is easier to recognize than Bunt, because the black, smutty ears become conspicuous as soon as they emerge from the leaf sheaths (Fig. 4). The spore masses quickly become loose and powdery, and are easily blown away by wind; consequently before long nothing may remain of the smutted ear but a bare central stalk. The spores behave quite differently from those of Bunt. They are carried about among the crop by wind at flowering time and if they happen to fall on the open flower of healthy plants they germinate and produce mycelium which grows into the young developing grain. There it remains apparently harmless, having no visible effect on the grain, so that healthy and infected grains are harvested, threshed and sown together. The fungus has however penetrated into the young bud which will grow into the seedling. When the infected grain germinates, the fungus inside it is carried up in the growing tip, though still with no obvious effect on the host. As the ear develops and the grains are forming, however, the fungus produces its black spores in them and these become visible as soon as the ear emerges from the sheath. Varieties of wheat differ in susceptibility to Loose Smut and several physiologic races of the fungus have been distinguished. In this country Vilmorin 27 and Hybrid 46 appear to be particularly susceptible.

The essential difference between Loose Smut and Bunt must be appreciated. In Loose Smut the fungus is present inside the grain, in Bunt it

occurs on the surface of the grain as spores; in other words, in Loose Smut the grain is *infected*, in Bunt it is only *contaminated*. In preventing Loose Smut, therefore, it is clear that fungicidal dips and dusts which do little or no more than kill spores on the surface of the seed are useless. The mycelium within the grain must be killed, and without injuring the grain itself. This can be accomplished by suitable heat treatment, but it is a troublesome process and the margin of safety a narrow one. By far the best method of dealing with the disease is to avoid it by making sure that seed grain is obtained from a crop quite free from Loose Smut. The National Institute of Agricultural Botany at Cambridge operate a Cereal Field Approval Scheme whereby crops can be inspected and certified for relative freedom from certain diseases, including Loose Smut.

Those who cannot obtain clean seed and who wish to try the warm water treatment, should put their seed grain into a sack, incompletely filled to allow for swelling, and place the sack in a vessel of warm (32°C) water so that it is just covered. The sack should be raised and lowered several times to make sure that the water reaches all the contents, and then left to stand for 4 hours. After standing, the sack is lifted out, allowed to drain a few minutes, and then submerged for 10 minutes in a tank of warm water. During this period the warm water *must* be kept between 52°C and 54°C, and for this a reliable thermometer is essential. If below 52°C (125°F), the mycelium will not be killed; if above 54°C (129°F), germination of the grain will be affected. When the sack is plunged into the warm water, the temperature of the latter will, of course, drop and this must be adjusted by adding boiling water. By moving the sack about from time to time uniform heating will be facilitated. After 10 minutes the contents of the sack are spread in a thin layer on a clean floor and allowed to dry. When large quantities are treated the seed should be cooled by plunging it immediately in a cold water dip before drying. It should be sown when dry.

The risk of injury involved in the warm water treatment depends not only on maintaining the correct temperatures but also on the mechanical condition of the grain, the conditions of pre-soaking and other factors. Recent attempts have been made to break away from the time-honoured treatment by omitting the pre-soaking and varying the temperature of the bath, by treating the moistened seed in closed containers which are rotated in a hot water bath, with or without the addition of alcohol or methylated spirit to the steeping water, and in other ways. Some of these methods have given promising results but they are still in the experimental stage. On the other hand, in some countries where Loose Smut is economically important, special machines have been devised for handling large quantities of seed, and in the United States of America and elsewhere co-operative or community plants have been introduced.

FLAG SMUT OF WHEAT

This smut (*Urocystis agropyri* (Preuss) Schroet.) is of importance in Australia, South Africa, the Punjab and China, and occurs also in the United States of America, South America, several countries in Asia and in southern Europe, but fortunately has not yet been seen in Britain. As the name implies, the smut is found mainly on the leaves and the leaf sheaths, on which

it produces long grey stripes that become black when the smut spores they contain are exposed. Affected leaves are twisted, the tillers stunted and deformed, and the plants often do not ear and may be killed outright. Infection may take place from spores present on the surface of the seed grain, as in Bunt, or from spores that fall to the soil and remain alive there, sometimes for several years. Flag Smut can be controlled by seed treatment with organo-mercury compounds, by the use of resistant varieties, and by avoiding wheat for a few years on land that has carried an affected wheat crop.

SMUTS OF BARLEY

Three distinct smut fungi may attack barley. One is a Covered Smut (*Ustilago hordei* (Pers.) Lagerh.), the spores of which contaminate the seed grain like those of wheat Bunt, and one is a Loose Smut (*Ustilago nuda* (Jens.) Rostr.) which infects the seed grain in the same way as Loose Smut of wheat. The third one (*Ustilago nigra* Tapke) has not yet been recognized in this country but is common in North America and has been seen in Palestine. It is peculiar in that it is a loose smut which contaminates the seed grain without infecting it, and is therefore readily controlled by seed dressings. Two barley smuts are recognized in Britain. Covered Smut is much less frequent now than it was twenty years or so ago though it is still occasionally serious on the calcareous soils in Orkney, Shetland and the Outer Hebrides. Loose Smut has become of increasing importance in Britain in recent years, but is of little economic significance.

Covered Smut is first recognizable in a crop when the blackened ear emerges from the leaf sheaths. Every ear of a diseased plant and every grain in the ear is generally affected. The substance of the grain is replaced by the black spore mass of the fungus, and this mass is usually held together by the skin of the grain and the husks that adhere to it, so that the ear remains intact and few spores are blown about by wind. The healthy and affected ears are harvested together. During threshing the smutted ears are broken up and many of the smut spores then liberated adhere to and contaminate the surface of healthy grains. From that stage onwards Covered Smut behaves exactly like Bunt of wheat (p. 7) and, like the bunt fungus, it can be prevented by disinfecting the seed grain with an organo-mercury fungicide before sowing. The method of treatment is the same as described under Bunt, except that some manufacturers recommend 2½ oz instead of 2 oz of dust for each bushel of seed grain.

The Loose Smut found in Britain behaves exactly like Loose Smut of wheat (p. 9). The smutted ears become obvious as soon as they emerge, the naked smut spores are blown about among the crop by wind, and the young developing grain on healthy plants becomes infected by these spores through the open flowers. The fungus is present inside the seed and can be killed only by a difficult and tedious warm water treatment. In general, the procedure to be followed is the same as that described on p. 10 for wheat. For winter varieties a four hour pre-soak in cold water should be followed by 10 minutes in water kept at 51–52°C (124–126°F). For spring varieties the pre-soak should be in warm water 32°C. (90°F.) followed by the 10 minutes in hot water at 51–52°C.

SMUTS OF OATS

Oats are attacked by a Covered Smut (*Ustilago hordei* (Pers.) Lagerh.) and a Loose Smut (*Ustilago avenae* (Pers.) Rostr.) but these fungi behave rather differently from the corresponding Covered and Loose Smuts of wheat and barley. For one thing the spores of Covered Smut do not all remain enclosed within the grain until harvest time, while those of Loose Smut sometimes remain intact until threshing. Consequently it is not always easy to distinguish the two smuts even under a microscope[1] and they are not often differentiated in this country. Loose Smut, however, is more common here than Covered Smut and occurs regularly in small quantity almost everywhere. Covered Smut is found most years on the *strigosa* varieties in mid-Wales and the Outer Hebrides, but is rare on *Avena sativa*. In addition to attacking the ears (Fig. 5), both smuts occasionally produce black stripes on the uppermost leaves. Several physiologic races of the two smuts have been distinguished in England and Wales and at least one of them is widely distributed.

The precise way in which infection of the host occurs is still a matter of opinion. It is generally agreed that spores of Loose Smut, which are mostly liberated during the flowering period, find their way by wind or other means on to the open flowers or between the glumes. Some of the spores of Covered Smut may behave in the same manner towards the end of the flowering period and subsequently, but with this smut the bulk of the spores is not liberated and therefore fails to reach the grain until it is threshed. It is also true that few or many of the spores germinate soon after reaching the open flowers or the threshed grain. Some workers maintain that the mycelium produced by these germinating spores penetrates into the glumes, the stigmas and anthers, and even the seed coat, and remains dormant there until sowing time. The fungus does not proceed beyond the seed coat and reach the embryo, as it does in Loose Smut of wheat, but the dormant mycelium is believed to become active when the seed is sown and to be mainly responsible for the infection of the young seedling. Others maintain that the dormant mycelium, if formed at all, is unimportant, and that infection arises mainly or exclusively from spores present between the grain and the husks that cover it, or adhering to the surface of the husks. Whatever the details of the process, active infection of the plant invariably takes place in the seedling stage. It occurs most readily when the soil is warm and dry immediately after sowing and is more likely to succeed in light than in heavy soils. A moist soil, on the other hand, greatly reduces the chances of infection occurring. Infection of the seedling does not necessarily result in smutted ears, for at times the mycelium fails to keep pace with the growing seedling. This may explain why some apparently healthy plants which produce sound ears will, after harvest, throw up weak tillers with smutted ears.

Both the oat smuts can be prevented by seed treatment with an organomercury fungicide as described for Bunt of wheat.

SMUTS OF RYE

Rye is susceptible to the two smut fungi that cause Bunt and Loose Smut of wheat. One of these — Bunt — has been found occurring naturally on rye

[1] The spores of *U. hordei* are usually smooth; those of *U. avenae* usually echinulate, i.e. bearing small spines. It may be doubted whether these two smuts deserve to be regarded as more than varieties of the same species.

in Britain, but only on two or three occasions. Another, and distinct smut, named *Urocystis occulta* (Wallr.) Rabenh., has proved troublesome in parts of Europe and North America, but is rare and slight in Britain, though known here since 1800. The disease needs watching, however, for a moderately bad attack occurred in Norfolk in 1943. Infected plants are stunted, darker green than usual, and may not come into ear. Long leaden-looking streaks concealing the smut spores develop on the stems, leaves and occasionally the glumes; the affected parts are often distorted, twisted and split. Infection takes place in the seedling stage from spores carried over on the seed or left in soil that has carried an affected crop. The disease can be prevented by seed treatment as for Bunt of wheat (p. 7) and by suitable crop rotation.

SMUT OF MAIZE

Maize Smut (*Ustilago maydis* (DC.) Corda) is prevalent in North and South America and probably occurs to a greater or less extent wherever maize is grown. Usually sporadic and variable, it may do much damage on land that has been cropped with maize for a number of years. The disease has been recorded in England several times but is of no significance here. Any part of the plant may be affected, but the fungus is always localized within the plant and gives rise to small or large galls on the leaves, stems and flower parts. These are white at first but become dark and ultimately black as the smut spores form within them. Under commercial conditions the disease is best controlled by a rotation that does not permit maize more than once in three years on the same land; the smut is not carried on the seed and seed disinfection therefore is of no benefit. Spread can be checked by removing and burning affected plants before the galls burst and liberate the spores.

Leaf Stripe and Allied Diseases

LEAF SPOT AND SEEDLING BLIGHT OF OATS

This seedborne disease is most serious in the colder and wetter districts of the west and north, especially Wales, the northern counties of England and south-west Scotland. It is, however, found throughout Britain, no doubt partly because seed oats are sometimes "imported" to the south and east from the west and north. The disease is caused by the fungus *Pyrenophora avenae* Ito & Kuribay., better known by the name of its imperfect or conidial state, *Helminthosporium avenae* Eidam.

There are two phases of the disease — the primary (Fig. 6) and the secondary. The fungus is carried with the seed either as spores on the surface of the grain or as mycelium in the husks and seed coat. As soon as the sheath (coleoptile) emerges from the seed the fungus attacks it, producing one or two very narrow brown stripes, just visible to the naked eye, along its full length. The coleoptile and the very young true foliage leaves wrapped up in it may be killed or so weakened that it fails to reach soil level (pre-

emergence blight), but more often the whole sprout survives and the foliage leaves successfully emerge above ground. The first leaf becomes infected from the sheath before it emerges, when it is frequently twisted or distorted. The second, third and fourth leaves become infected in the same manner from the preceding leaf, but are rarely distorted. Thus, as the first four leaves begin to expand they show a pale green stripe or a line of pale green dots which later link up to form a stripe. The stripes soon become brown or reddish-brown conspicuous streaks down the middle or margin of the leaf. If conditions are favourable, spores are produced on the brown dead tissues and during April and early May these may infect the healthy portions of the leaves to give isolated brown spots or blotches, which sometimes have a purple margin. Many seedlings do not survive this primary phase (seedling blight) and consequently the stand or braird may be a thin one. Plants affected by, but surviving, the primary phase generally tiller badly; they are stunted, produce fewer spikelets with the lower ones often blighted or "blasted", and give poor yields. The fifth and subsequent leaves are usually healthy when they unfold and for a time the plant appears to grow away from the disease. After about a month or six weeks, however, and generally in June or July, the secondary phase begins on the upper leaves. It takes the form of minute, scattered flecks which enlarge into roundish spots or elongated blotches involving much of the middle or edge of the leaf. The spots are few, brown in the centre, foxy-red towards the outside and often have a purplish margin. The earlier formed ones are a result of infection by wind-blown spores produced on leaf tissues killed during the primary phase. Fresh crops of spores arising on these spots then serve to spread the disease among the crop and from the leaves to the spikelets. As a rule the secondary phase has little effect on yield but it leads to seed infection, for the fungus passes from the uppermost leaves into the husks and the seed coat of the developing grain or is carried over as spores on the surface of the grain.

The prevalence of Leaf Spot and Seedling Blight is very dependent on weather conditions. Soil temperatures govern the primary phase and atmospheric humidity the secondary phase. Where soil temperatures are low, pre-emergence blight and seedling blight will usually be severe if infected seed is sown. On the other hand, the amount of soil moisture at this stage is a relatively unimportant factor in determining infection. Later, as temperatures rise, the balance shifts in favour of the plant and for a time the disease is checked; but where rainfall is high or humid conditions prevail in June and July, the secondary phase soon appears, makes rapid progress and increases the risks of harvesting infected seed. None of the varieties of oats commonly grown is particularly resistant to infection.

The disease is almost invariably introduced with the seed, though it is possible that the fungus may occasionally be carried over from one season to the next on infected oat residues left in the soil. This would be the more likely if the fungus commonly produced the resistant black bodies (perithecia) of its perfect stage on the stubble of an infected crop, but up to now the perithecia have been seen only on a few occasions in Scotland.

Leaf Spot and Seedling Blight can be effectively controlled by disinfecting the seed before sowing with an organo-mercury fungicide in the manner described under Bunt of wheat (p. 8). This should be carried out every year as a routine measure, and should never be omitted if the seed is obtained from one of the wetter districts. It is true that severe attacks can often be

averted by sowing untreated seed as late as possible in spring, but such a practice renders the plants more liable to severe damage by frit fly (*Oscinella frit* L.). Frit fly damage can be avoided by sowing early, so that if the seed is suitably disinfected the way is clear to control both pest and disease. Both warm water and electric heat treatment have been tested, but neither is effective.

LEAF STRIPE OF BARLEY

This disease, at one time common and damaging particularly in the north, is now only rarely seen in Britain. It is caused by the seedborne fungus *Helminthosporium gramineum* Rabenh.[1]

With one or two significant differences Leaf Stripe follows the same course as Leaf Spot of oats. As with Leaf Spot the fungus is carried as spores on the surface of the grain or as mycelium in the husks or seed coat, and from there it invades the outer part of the emerging sheath (coleoptile). It passes through to the inner surface of the sheath and forms a pale stripe on the first leaf as it pushes upwards out of the sheath. The second leaf in turn becomes infected from the enclosing sheath of the first, and so on. If the attack is a severe one the young seedlings may be killed outright: otherwise each leaf as it expands shows one or more long and narrow brown or yellow stripes (Fig. 7) sometimes running from the base almost to the tip. The stripes usually pass through a series of colour changes from pale green to yellow and then to rich brown; sometimes all three stages can be observed on the same leaf, the brown portion being at the tip. The striping does not cease with the fourth leaf as in Leaf Spot of oats; as a rule all the leaves show the stripes, though the later formed ones sometimes escape. The ear itself frequently becomes infected in the same manner before it emerges. It may never emerge at all or, if it does, some or all of the grain may not develop ("blindness"). Such grain as is formed is usually discoloured and becomes contaminated or infected with the fungus. Occasionally the growing point itself is killed and the fungus may enter the stem from the leaf sheaths, causing discoloration of the nodes, but the secondary leaf spot phase of attack, so conspicuous in Leaf Spot of oats, is not common in barley.

The effect of Leaf Stripe is therefore a threefold one. It kills the young seedlings and is an important contributory cause of thin stands; it reduces the vigour of mature plants; and it causes partial or complete blindness of the ears. Six-rowed barleys are more susceptible than two-rowed varieties and winter-sown crops suffer worse than spring-sown ones, probably because the disease is favoured when low soil temperatures and other adverse weather conditions impede the early growth of the plant.

Like Leaf Spot of oats, this disease can be controlled by seed treatment with an organo-mercury compound. As the fungus can remain alive in barley stubble for at least a year there is a risk that infection might occur when barley follows barley, even if the seed has been properly disinfected.

[1] The perfect state of this fungus is *Pyrenophora graminea* Ito & Kuribay., but it has not been found in Britain.

NET BLOTCH OF BARLEY

Net Blotch (*Helminthosporium teres* Sacc.[1]) is widely distributed on barley in Britain, but is unimportant. The fungus is seedborne and the early stages of infection are the same as in Leaf Stripe, but it is usually only the first leaf that shows a typical stripe. The spores produced on this stripe, and carried to leaves subsequently developed on the same plant or to leaves on other plants, give rise to the characteristic net blotch by which the disease can be recognized. Each blotch is brown, irregular in shape, generally long and narrow, or rectangular, and on close inspection is seen to consist of a network of dark lines criss-crossed over a paler background. The disease spreads most readily in the wetter districts and in damp seasons, and ultimately passes over to the ears and the grain. It can be prevented by seed treatment with an organo-mercury compound (see p. 8).

LEAF BLOTCH OF BARLEY AND RYE

This disease, called Scald in America, was not recognized in Britain until 1919. It is not uncommon on barley and frequent on rye in East Anglia, and is widely distributed on both hosts in the midlands, south, south-west and in Scotland, but is less common in the north of England. Certain grasses including soft brome grass (*Bromus mollis*) are also affected and abroad the disease has been seen sparingly on wheat. It is caused by the fungus *Rhynchosporium secalis* (Oudem.) J. J. Davis.

The blotches may appear on any part of the leaf, though they commonly start at the junction of leaf blade and sheath. When fully formed they are light grey with a dark brown margin, generally lentil shaped, up to $\frac{3}{8}$ in. long and $\frac{1}{4}$ in. broad, sometimes extending to cover the greater part of the leaf (Fig. 8). At times the individual blotches enlarge slowly in a series of stages and then they become zonate with concentric brown rings. The disease is seldom seen before May or June and often the plants grow away from it later. Spread from plant to plant takes place by spores that are produced in large numbers on the blotches. Yield and quality of the grain may be adversely affected to some extent, but Leaf Blotch appears to be of no great economic importance.

It is uncertain how the disease survives from one season to the next. It does not appear to be seed- or soilborne, but is often abundant on self-sown barley plants in autumn and may survive the winter on them. Opinions differ about the ability of the fungus to pass from one host to another and the subject needs further investigation. Leaf Blotch cannot be prevented by seed treatment.

[1] The perfect state of this fungus, *Pyrenophora teres* Drechsl, was found in England for the first time in 1949 and has since been recorded on several occasions. A pycnidial stage has been seen on old barley straw in and around Cambridge.

Foot and Root Rot Diseases

TAKE-ALL

Take-all is one of the most serious diseases of wheat. It occurs in most parts of the world in temperate zones, and in countries where continuous wheat growing has been practised, such as Australia and North America, it has caused heavy crop losses. In Britain, Take-all has been known since about 1900 and has probably been present much longer. It is caused by two distinct though closely related fungi. One of these, named *Ophiobolus graminis* (Sacc.) Sacc., readily attacks wheat, barley and certain grasses, while rye is fairly resistant to it and oats almost immune. This form of Take-all is widely distributed in Britain but occurs most frequently in the lighter alkaline soils overlying chalk or limestone, such as are found on the Yorkshire and Lincolnshire Wolds, the Chiltern Hills, and in East Anglia, Wiltshire and Hampshire. It may develop in soils that have been heavily limed but it is not common on heavy land or on soils in a high state of fertility. Less is known about the other fungus, *Ophiobolus graminis* (Sacc.) Sacc. var. *avenae* E. M. Turner[1], which is found mainly on oats and is largely restricted to those areas—Wales, the north and north-west of England and Scotland — where oats is the chief cereal crop. It is capable of attacking wheat and barley and seems to be largely responsible for attacks of Take-all on wheat reported from Wales; it has also been found on turf grasses. The account given below refers in the main to the wheat disease caused by *Ophiobolus graminis*.

Take-all is most likely to appear when the rotation is too short so that wheat follows wheat or barley, but it is sometimes also severe in wheat following old weedy grassland, because the fungus can be carried on the roots of a number of weed grasses. The disease sometimes develops in a young wheat crop as patches in which the plants are either killed outright or remain backward and stunted with yellowing leaves, and may then cause partial failure of the crop. As a rule, however, although the fungus may have been active on the roots for some months, the disease is not noticed until after heading, when individual plants or groups of plants die. Such plants can be recognized without difficulty by the white or bleached appearance of the empty or almost empty ears, which contrast strongly with the normal colour of the ripening ears, and plants so affected are called "Whiteheads". After a time, especially in wet seasons, the ears may become more or less covered with a black mould, though this is purely secondary (p. 27). Not all whiteheads are a result of Take-all, but a true Whitehead plant can usually be recognized, on pulling it up, by the presence of a characteristic black discoloration at the base of the stem, which is most evident when the leaf sheaths are pulled away (Fig. 9); the roots are also blackened and break off easily. The whitehead condition is not conspicuous in barley, the ears of which normally ripen white, but the disease can be

[1] To distinguish the two fungi it is necessary to measure the ascospores (those of var. *avenae* are longer than those of *O. graminis*) or to carry out a biological test by growing wheat and oat seedlings in pieces of infected stubble, and examining the roots of the seedlings to see if infection occurs.

detected, often in patches, by poor growth and yield, in conjunction with the blackening of the stem base. In wet seasons, black spore cases (perithecia) of the fungus may be formed on the stem base, though more often they are found only on the stubble after harvest. They do not appear to play a significant part in the spread or maintenance of the disease.

Ophiobolus graminis remains alive in the soil on the root and stubble residue of a previously infected crop or on the roots of infected weed grasses, especially those with creeping underground stems. When wheat or barley is sown, the fungus in the soil attacks and spreads along the young roots. The growth of the plant is not materially affected until the fungus reaches the crown and bases of the main stem and tillers, and then the plant may soon be killed. The rate of spread along the roots, and consequently the severity of the disease, depend largely on soil conditions. Spread is rapid in light, loose or moist soils and slow in dry soils. The disease is therefore apt to be worse in years with high spring and summer rainfall, and slight in dry seasons.

The most effective method of controlling Take-all is to starve out the fungus in the soil and this can best be done by suitable rotation of crops. The precise rotation to be followed will vary with farming practice in the district, but too frequent cropping with wheat and barley should always be avoided. Crops other than cereals are not attacked and one year without a susceptible crop is normally sufficient; on heavily contaminated land two years may sometimes be necessary. Oats can replace the susceptible barley where Take-all is caused by *Ophiobolus graminis*, but in districts where oats are attacked by the *avenae* variety it is important to avoid too frequent cropping with oats. Although ley grasses can be infected, experience has shown that following a one or two year grass-clover ley the incidence of Take-all on land previously contaminated is reduced to a sufficiently low level for a good crop of wheat or barley to be taken immediately afterwards.

It is sometimes difficult to avoid growing two or three wheat or barley crops in succession on the same land; when this is necessary, it is essential to maintain the land in a high state of fertility by generous application of chemical fertilizers. This will encourage a strong plant capable of putting out new roots to replace those destroyed by the fungus. When two cereal crops are grown in succession on light land the second should be spring-sown, especially when any signs of the disease have been seen in the first crop. The Chamberlain system, introduced by Mr. F. P. Chamberlain of Benson, Oxfordshire, is worth attention where it is desired to take two or three spring barley or wheat crops in succession. Trefoil (*Medicago lupulina*), a mixture of trefoil and ryegrass or ryegrass alone, is sown with the barley at the rate of 20 lb per acre and is ploughed in during the late winter as a preparation for the next barley crop.

Another important aim in control should be to keep down perennial grass weeds, and especially couch (*Agropyron repens*), Yorkshire fog (*Holcus lanatus*), creeping soft grass (*Holcus mollis*) and bent grass (*Agrostis* sp.). Attention should also be paid to proper cultivation. It is best to start preparing the land for wheat as early as possible. The firmer the seedbed, the slower the fungus will spread along the roots. In the same way the seedbed will have a better chance of becoming consolidated by early autumn rains if drilling is carried out late, in October or November, on the lighter soils. Provided the seedbed is well prepared and grass weeds are kept down, there

is no particular advantage in early ploughing-under of the stubble after harvesting a diseased crop.

As far as is known there are no varieties very resistant to Take-all.

EYESPOT

Eyespot has doubtless existed in Britain for a long time, though it was not recognized as such until 1935. The disease is caused by the fungus *Cercosporella herpotrichoides* Fron. It occurs throughout Britain but is most widespread in the eastern and midland districts of England where wheat and barley are prominent in the rotation, and in the Lothians, Fife and Morayshire. The climate, it is true, is more favourable to Eyespot in the western half of the kingdom, but here oats form the main cereal crop and they are much less susceptible to the disease. Winter wheat and barley suffer most, especially where sown early; spring sown crops are also infected but usually too late to do much harm unless conditions are very humid, and rye is not often attacked. It is not known to what extent wild grasses are of importance in carrying over the disease. Wild oats and some other grasses may be attacked by it, and the fungus may sometimes pass from them to wheat and barley.

In autumn and early spring, the outer leaf sheaths of young wheat and barley plants become infected near soil level by spores of the fungus that are produced on bits of diseased stubble left on the surface of the soil from a previous crop. The fungus passes inwards from sheath to sheath and, if the weather is mild and moist, progress is so rapid that some of the tillers or even whole plants may be killed outright. This leads to a thin stand. Usually the attack is less rapid; most tillers survive but the fungus gradually works inwards to the straw, on the lower part of which it forms the typical eyespot. This is an oval, brown bordered spot, shaped rather like an eye, with a blackish dot in the middle; it can be found by pulling away the leaf sheaths at the base of the plant and may sometimes be visible on the sheaths themselves. If diseased straws are split open near the eyespot the grey mycelium of the fungus can often be seen within the cavity. Care is needed to distinguish Eyespot from the relatively minor trouble known as Sharp Eyespot (p. 23).

In the early months of the year, up to the end of April, fresh crops of spores are produced on the affected plants and these serve to spread the disease through the crop. Generally speaking, however, the disease is not apparent to the casual observer until the end of June or later. The fungus naturally has a weakening effect on the base of the plant; it ultimately passes right through the straw, causing it to bend or twist in the region of the eyespot (Fig. 10), and as a result, from about Mid-June onwards, many individual straws topple over and lie in all directions among the upright ones. This gives rise to the condition known as "straggling." If the crop is heavy and the variety a long-strawed one the effect may be more serious, for much or most of the crop may lodge. This kind of lodging is quite distinct from lodging due to wind and storm, excess of nitrogenous manuring, poor root development and other non-parasitic factors, but it may be equally common. Moreover, the straws fall in all directions so that the crop is very difficult to cut. Yields may be reduced by one third or more, individual

grains are smaller and the amount of tail corn is disproportionately high. Whiteheads similar to those resulting from attack by Take-all (p. 17) and other foot-rotting fungi may also be associated with this disease.

Eyespot is often abundant on good wheat land under conditions that favour luxuriant growth, especially if wheat and barley are grown frequently The worst outbreaks occur where successive crops of wheat and barley are taken. It is seldom serious, however, in the first or second crops after grass. Wet seasons, heavy, moist or badly-drained soils, and thick stands favour the disease. A laid strip is often seen, for instance, at the drilling headland where a certain amount of inevitable cross-drilling leads to a thicker plant. Eyespot may also be found on light, well-drained soils, but here the affected outer leaves often dry up and are sloughed off before the fungus penetrates deeply, and the plants then grow away from the disease. The fungus persists in the soil, on old stubble and on self-sown plants for some time; a break of two years nearly always reduces infection to a harmless level but after a bad attack it is often wise to leave four or five years before planting wheat or barley again.

The best way to avoid Eyespot is to reduce the frequency of wheat and barley in the rotation. Where leys can be alternated with arable the disease is not likely to be troublesome. Nitrogenous manures give luxuriant crops in which the disease spreads readily but does less damage than to poorly nourished crops. Thus, good manuring favours the plant and enables it to yield better in spite of disease, though it increases the tendency to lodging. Where Eyespot has been severe, therefore, it may be advisable to select short-strawed varieties instead of long-strawed ones and manure them well in order to obtain the higher yield without serious risks of lodging. The variety Cappelle-Desprez shows some degree of resistance to the disease. Good drainage is essential; late, thin sowing, spring sowing and wider spacing are all palliative measures which must be balanced against their disadvantages in other directions. There is some experimental evidence that spraying the crops with sulphuric acid[1] (12½ per cent by volume applied at 100 gallons per acre, in spring to control weeds and check proud growth, may incidentally reduce the amount of Eyespot, but it may be ineffective and do more harm than good if applied after mid-March.

BROWN FOOT ROT AND EAR BLIGHT

These diseases are found in most parts of Britain and occur mainly in heavy, poorly-drained acid soils. They vary in severity from year to year and are rarely serious except in the north of England, in Scotland and in individual fields elsewhere. Winter wheat and barley suffer most, but oats and rye may also be attacked.

Brown Foot Rot and Ear Blight are caused by fungi of the genus *Fusarium*[2] which live in the soil and attack the roots of cereals and other plants. Many cereal plants, particularly wheat and rye, are killed outright in the young seedling stage "seedling blight" and as a result an affected

[1] Commercial strength 77 per cent.

[2] *Fusarium nivale* W. G. Sm. Sacc. and *F. nivale* Auct. are the most common species, but *F. avenaceum* Fr.[1] Sacc. and sometimes other species play a part A similar disease caused by *Gibberella zeae* Schw. Petch (conidial state *Fusarium graminearum* Schwabe[1] is dealt with on p. 21.

1. (*Top*) Wheat ears : left hand one healthy, the other two bunted
2. (*Bottom Left*) Wheat : (left) two healthy grains ; (right) two bunted grains or "butts"
3. (*Bottom Right*) A single "butt" broken to show the black mass of bunt spores

4. Loose Smut of Wheat

5. Loose Smut of Oats

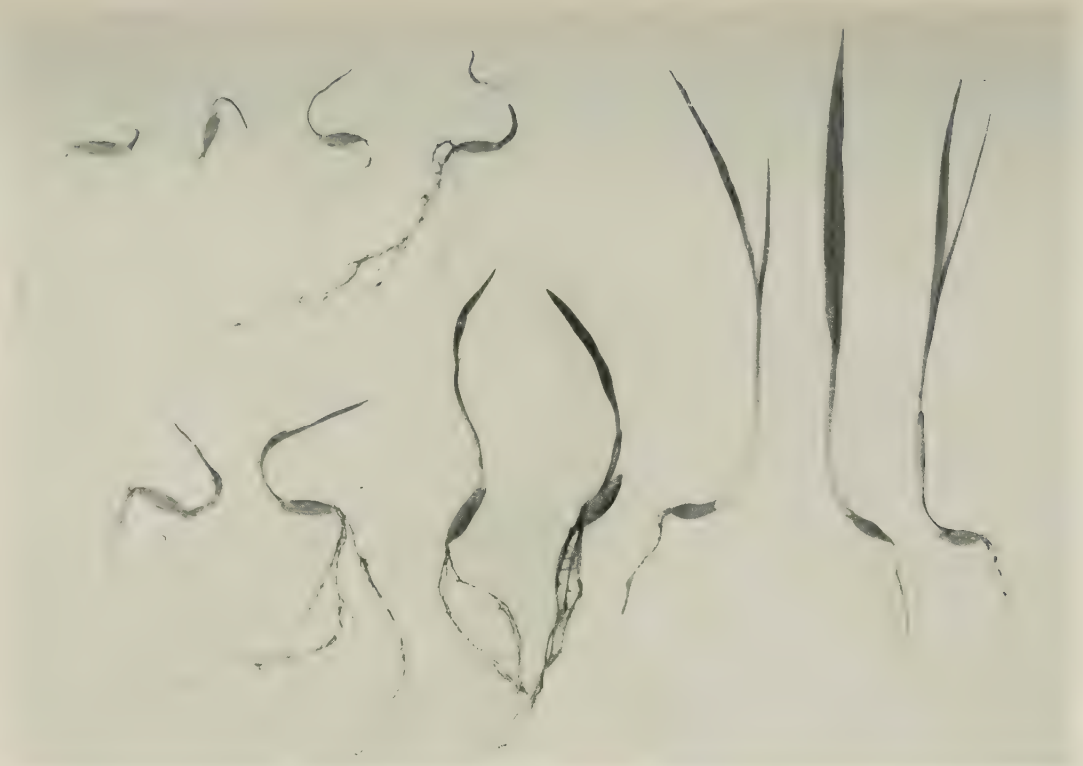

Photo: School of Agriculture, Cambridge

6. Stages in the seedling infection of Oat with Leaf Spot and Seedling Blight (*Helminthosporium avenae*)

7. Leaf Stripe of Barley; showing the stripes on the leaves

Photos : School of Agriculture, Cambridge

8. Leaf Blotch of Barley

9. Take-all of Wheat. The leaf sheaths have been removed to show the blackening of the stem base

10. Eyespot of Wheat, with kinking at the eyespot lesion. The lowest part of the stem and the roots are healthy (of. Fig. 9)

11. Oat Scab. Spikelets bearing perithecia of *Gibberella saubinetii*

12. Wheat Scab on the ears

13. Barley grains bearing perithecia of *Gibberella saubinetii*

14. Wheat ears attacked by Twist

15. Ergot on ears of Rye

16. A single germinating ergot with its fruiting bodies (enlarged

17. Oat leaves showing the symptoms of Manganese Deficiency Disease

18. Brown Neck of Wheat

crop shows a thin stand in spring. Others grow on but show yellowish leaves with withered tips; the root systems of such plants are poorly developed and some or all the roots are brown and rotten. The rot also extends into the base of the stem and the amount of damage done depends on the rapidity with which this brown foot rot condition is reached. Some plants fail to ear and others form ears which later topple over, but most of them remain standing though the ears contain relatively few small grains or are empty and bleached ("deaf ears" and "whiteheads"). White or pinkish spore masses of the *Fusarium* are produced on the affected stem bases, and these spores when carried about among the crop may infect the straw and ears to produce the Ear Blight stage sometimes prominent in wet seasons. Under moist conditions spore masses soon develop on the affected ears and they are sometimes so abundant on wheat and barley as to merit the name "red mould" which is often given to this stage. In wet seasons the deaf ears and whiteheads usually become covered with a secondary black mould (p. 27) as in Take-all.

As already stated, the species of *Fusarium* concerned live in the soil, and one or other of them is perhaps present in most soils, persisting on dead residues from cereal crops or from the many other crop and weed plants susceptible to attack by them. As a rule, however, they do not infect the roots and stems of cereals to any extent unless the soil is sour, wet, or poorly drained. The disease may also be carried over with the seed, for grain from plants affected with Ear Blight may be contaminated or actually infected by the *Fusarium*. Effective control of Brown Foot Rot and Ear Blight is difficult. Seed treatment with an organo-mercury dust has some beneficial effect because the dust kills most of the *Fusarium* spores present on the outside of the seed grain. It will not kill the mycelium inside infected seed, however, and has little or no effect on infection from the soil, which is probably much more important. Crop rotation is of limited value but much can be done to minimize loss by ensuring good growing conditions and adequate drainage. None of the commercial varieties of wheat and barley shows any marked resistance.

SCAB

It is convenient to deal with this disease separately, for there are certain special features about it, but in general its behaviour is similar to that of Brown Foot Rot. Scab is found on wheat, barley, oats and rye in many parts of the world and is often destructive, for instance in the central and eastern areas of the United States. It was first recognized in Britain on wheat in 1928 and has since been found also on barley and oats, chiefly in Wales, the north of England and Scotland. So far most of the attacks reported in the British Isles have been slight though an epidemic of Scab or Ear Blight developed on wheat in Eire and on late harvested oats in mid-Wales in 1942.

Scab resembles Brown Foot Rot in that it is caused by a species of *Fusarium* which invades the roots of cereals from the soil and either kills young seedlings outright (Seedling Blight) or so weakens the plants that they produce badly filled ears; if the weather is warm and moist at flowering time or when the ears are filling, the fungus produces typical Ear Scab or Blight, and it is this phase of the disease that is perhaps the most destructive one. The *Fusarium* differs from the species responsible for Brown Foot Rot in that, in addition to producing pink or reddish spore masses, it forms small bluish-

black bodies on the infected ears (Figs. 11 and 12) and on the stubble. These bluish-black bodies are called perithecia; they contain a second kind of spore and represent the perfect state of the fungus, which is named *Gibberella zeae* (Schw.) Petch.

Infected grains are badly shrunken, wrinkled and discoloured, and when spores of the *Fusarium* are present in abundance on them they have a pink or reddish appearance, especially at the germ end. With the aid of a hand lens the bluish-black perithecia can often be detected on the surface of the grains. (Fig. 13). Scab affects quality and feeding value of the grain as well as yield. The growth of the fungus in the grain causes chemical changes which result in the accumulation of substances that produce vomiting in pigs fed with infected grain and in human beings when they eat foodstuffs prepared from infected grain. The emetic effect is unimpaired even when the grain is four years old, long after the fungus present in it has died.

Scab persists through the winter on cereal residues in the soil or may be carried over with the seed. The perithecia eject their spores in spring or early summer and these play a large part in starting a fresh attack when weather conditions are favourable. The disease cannot be entirely prevented by any known treatment. A good crop rotation will lessen the risk of soil infection and seed treatment with an organo-mercury dust (p. 8) will reduce the amount of infection carried with the seed. Grain containing an appreciable quantity of infected material is unsuitable for preparing food products for human consumption or as pig food, whatever its age. Horses refuse badly scabbed grain, but cattle, sheep and poultry are unaffected by it.

OTHER FOOT AND ROOT ROTS

In addition to the parasites that cause the four diseases just described there are a number of soil fungi which are sometimes found in Britain associated with diseased or unhealthy cereal crops. One or two of them are active parasites which, though at present of little or no account in this country, do much damage abroad; the rest appear to be merely secondary organisms that grow on the roots and stem bases of plants killed or damaged by diseases, such as Take-all and Brown Foot Rot, or in some other way. Brief notes on these fungi are included chiefly for the information of those engaged in advisory work on cereal diseases.

Helminthosporium

Several species of *Helminthosporium* may be associated with Foot Rot, but the only common one is *H. sativum* Pamm., King & Bakke. This is one of the most important causes of Foot Rot in the wheat areas of North America, but it is not common in Europe and has been seen only two or three times in Britain on wheat and barley, and once on rye. The disease caused by *H. sativum* tends to develop in large or small patches in the field. Wheat, rye and barley are affected by it, as well as certain grasses. The fungus produces dark brown lesions on the roots and, if conditions are favourable to its attack, the seedlings may be killed before or soon after emergence. More often the plants grow to maturity, but the fungus slowly spreads through the roots, causes a light brown discoloration and decay of the stem base and, under certain conditions, may produce elliptical brown spots on the leaves, leaf sheaths and glumes. The heads of affected plants are poorly filled and

become covered with secondary black moulds (p. 27). Wheat grain from an attacked crop is frequently affected with Black Point (p. 27). Seed treatment with an organo-mercury fungicide (p. 8) will kill spores adhering to the seed but not the mycelium of the fungus that is present in the tissues of black-ended grains. Thus seed treatment may check but does not eliminate the disease, and suitable crop rotation is a better method of dealing with it.

Following widespread cultivation in North America of the oat varieties bred from the variety Victoria and inheriting its resistance to Crown Rust, a new foot rot disease caused by *Helminthosporium victoriae* Meehan & Murphy caused considerable economic loss there. This fungus has not been recorded in Britain. Infected seedlings show necrosis at the base of the shoot and striping or reddening of the leaves. On mature plants, rotting of the stem and roots is a most characteristic symptom and velvety spore masses develop on the lower blackened nodes. Severe infection weakens the culms and lodging frequently occurs. The fungus is both seed- and soilborne. Seed treatment with organo-mercury dusts is effective unless the treated seed is sown in contaminated soil, when very little or no protection is afforded by the treatment. *H. victoriae* has occasionally been found growing as a saprophyte or a weak parasite on a number of grasses and a few other hosts such as sorghum and soya bean.

Corticium

One of the commonest of soil fungi is *Corticium solani* (Prill. & Delacr.) Bourd. & Galz., better known perhaps by the name given to its mycelial state, *Rhizoctonia solani* Kühn. It attacks a wide range of hosts but is at present only of minor importance in cereal cultivation though in certain parts of Australia it has caused appreciable losses among wheat and oats. This fungus has been the cause of partial failure in a number of barley crops in Norfolk and has attacked wheat and oats both there and elsewhere in this country. *Corticium solani* attacks the plants in the seedling stage and kills the seminal roots and the first formed crown roots. Many plants recover but they remain backward and stunted, produce a few tillers, and mature late. The disease occurs in well-defined patches that may be only a foot or two in diameter or cover $\frac{1}{2}$ acre or more. The leaves are erect, rolled, and often have a purplish tinge, which can be seen from a distance ("Purple Patch"). At harvest time the backward patches can usually be distinguished by their green colour.

A more common symptom produced by *Corticium solani* is known as Sharp Eyespot, to distinguish it from the much more serious Eyespot caused by *Cercosporella herpotrichoides* (p. 19). The spots, which may be present several inches up the stem, are more or less superficial, somewhat asymmetrical, with more clearly defined and less regular margins than in true Eyespot, and bear brownish-purple instead of black mycelial patches in the centre. Sharp Eyespot is fairly common on wheat in Britain but it is rarely present on more than one per cent of the straws in a crop; it has also been found associated with deep lesions on oats.

Leptosphaeria

Species of *Leptosphaeria*, particularly *L. herpotrichoides* de Not., may occasionally be found fruiting on stubble or on the bases of plants killed, for example, by Take-all. Under these conditions they are to be regarded

as secondary organisms invading dead or dying tissues. It is not improbable, however, that under some conditions one or more species of *Leptosphaeria* may become actively parasitic on cereals. On the Continent, for instance, *L. herpotrichoides* has been regarded as the cause of a foot rot that may do considerable damage, and about thirty years ago the same species or a closely allied one was considered, by those well qualified to judge, to be responsible for the death of small patches of wheat or even as much as 30 per cent of a wheat crop in different parts of England. Affected plants showed a brown or black rot at the base of the stems and many of them died soon after flowering. Since then these fungi have been recorded here from time to time, mostly on wheat, but the precise significance they have in the pathology of cereal crops remains to be studied.

Pythium

The name Browning Root Rot has been applied to a disease of wheat that has proved troublesome in the Canadian prairie lands, particularly in soils with a low phosphorus and high nitrogen content. Oats and barley are also susceptible to it. Patches in the crops turn yellow and brown in June, and although affected plants often recover and give a reasonable yield, they usually tiller poorly and remain stunted. Browning Root Rot is caused by one or other of several species of *Pythium*, the commonest of which is *P. arrhenomanes* Dreschsl. These fungi live in the soil and attack the underground portions of the young seedlings, producing browning of the root tips and brown lesions along the main roots. The disease is usually worse in crops after fallow than in those sown on stubble land, and in seasons when a period of cold wet weather in spring is followed by drought and heat. Phosphates increase rooting capacity and in soils with a high phosphorus content the plants are better able to produce roots to replace those killed by *Pythium*. Consequently, the plants show little effect of the disease and thus appear to be more resistant in such soils. None of the common wheat varieties grown is very resistant, however, and control depends largely on providing the soil conditions necessary for the production of vigorous seedlings. In particular phosphorus deficiency must be rectified, and once this is done nitrogenous manures, particularly farmyard manure, have a beneficial effect.

Browning Rot Rot has been given little attention outside Canada. Its presence has been confirmed on wheat in several English counties as well as on oats in Devon, but the extent to which it affects crop yields here is not yet known.

Wojnowicia

Some attention has been given abroad to a fungus named *Wojnowicia graminis* (McAlp.) Sacc., which is generally looked upon as at most a very weak parasite that occurs mainly on wheat plants attacked by Take-all, Eyespot, or some other disease. In Britain it was first recognized on wheat in Hampshire in 1934 and has been seen on several occasions since then, but is of no practical importance.

Gibellina

Gibellina cerealis Pass. causes White Straw Disease of wheat in Italy; it has also been recorded from France and China. In Britain the fungus was first seen in 1935 and has been seen every year since 1937 but only at the

Rothamsted Experimental Station on a plot on which wheat has been grown alternately with fallow since 1856. It can usually be recognized in May by the presence on the lower part of the stem of round or oblong, white, felt-like spots, each with a conspicuous dark margin.

Miscellaneous Fungus Diseases

MILDEW

It is surprising that until recently so little attention has been given in this country to a fungus as common and well established as Mildew (*Erysiphe graminis* DC.) of cereals. It attacks wheat, barley, oats and rye, as well as most grasses, but exists in a number of physiologic races, each as a rule restricted to its own particular host or group of varieties. so that a badly affected wheat crop, for instance, is not a source of danger to a neighbouring barley crop. On wheat the fungus can often be seen in February as superficial, dirty white or brown mats of mycelium present on the lower leaf sheaths. Spores are produced on this mycelium and fresh patches of Mildew soon develop, first on the lower leaves and then higher up the same plants or on neighbouring plants. These patches are white at first and later darken or become brown. Following early infection the lower infected leaves may become yellow and shrivel. Later infection of other leaves, including the flag leaf, and of the ears, though more conspicuous is less damaging. Mildew becomes general at any time between May and August. As the season advances small black spore-cases (perithecia) containing a second kind of spore are formed in large numbers among the brown mycelial mats. Mildew may also be severe on barley, and on oats; it is not often seen on rye.

The development of mildew is associated with rapid growth of the host plant and consequently the disease is usually most serious on spring-sown crops, particularly late-sown ones, when the period of active growth has occurred after about the end of May. Generous or late applications of nitrogen leading to increased growth in late spring also favours infection. Mildew undoubtedly reduces yields considerably particularly on spring-sown crops. Reductions in yield of 10 20 per cent have been recorded in spring-sown barley. Varieties differ widely in their susceptibility, but the same variety may behave differently in different parts of the country and for this reason it is not possible to prepare reliable lists of susceptible and resistant varieties.

The main source of infection in spring appears to be the mycelial mats formed on winter wheat and self-sown plants in late autumn. The perithecia overwintering on the remains of a previous year's crop doubtless play a part also, but most of the spores they contain are liberated in autumn to start the mycelial mat formation on the new seedlings. No practical measures of controlling Mildew are known. Too thick sowing and unbalanced manuring should be avoided; potash deficiency can increase susceptibility to mildew.

Successful control of mildew on a plot scale has been obtained with lime sulphur sprays.

ERGOT

Ergot (*Claviceps purpurea* (Fr.) Tul.) is not a serious disease in Britain but is present to a slight extent each year in many, if not most, rye crops. The few severe outbreaks that do occur are found mainly in Yorkshire and the western half of the country. Wheat and, to a less extent, barley are sometimes attacked, but Ergot is very rare on oats; on the other hand it is very common on certain wild and cultivated grasses.

The familiar stage of the disease is the ergot itself, which is a horn-shaped purplish-black body, with a white interior, that develops in the ears in place of some of the grains (Fig. 15). It consists of compact masses of fungus mycelium, is anything up to three-quarters of an inch long, and matures about the same time as the healthy grain. The ergots either fall to the ground and remain there over winter or are harvested and threshed with the crop, and so return to the land with the seed. Those on or near the soil surface germinate about the time cereals are in flower to produce one or two or as many as fifty flesh-coloured fruiting bodies, ¼–1 in. long, which look like miniature drumsticks (Fig. 16). The spherical heads of these bodies contain spores (ascospores) which when discharged are carried by wind or insects to the open or nearly open flowers. Here they germinate and infect the developing ovaries by way of the stigmas. In about a week a sticky liquid exudes from the young florets. This is the honey-dew (*Sphacelia*) stage; the liquid consists of innumerable spores of a second kind and these are carried by insects and probably also in rain splashes from one flower to another. Meanwhile the infected ovaries, instead of producing normal seed, become converted into a tight mass of fungus mycelium which grows longer, becomes hard and dark, and finally emerges from the flower as a mature ergot.

The extent to which the disease occurs is closely bound up with weather conditions during the flowering period. This is rather short — about a week or ten days — and as moisture is necessary for the spores to germinate on the stigmas, more Ergot can be expected in years when cool, wet weather prolongs the flowering period than when the weather is hot and sunny at that stage (late June or early July). Rye Ergot has been general only in the few years (e.g., 1927 and 1928) when the weather has been bad at flowering time, though there appears to be a "residual" effect for a year or two after a bad season, due presumably to the number of ergots that drop to the ground and remain there to provide a source of infection the following year.

Ergots have a medicinal value, but they contain poisonous substances which may produce two kinds of ergotism, the convulsive and the gangrenous, occurring respectively east and west of the Rhine. There appears to have been only one occurrence of typical human gangrenous ergotism in England (near Bury St. Edmunds 1762), but a very mild though rather extensive epidemic of ergotism was reported from the Manchester area following the unusually heavy attack of ergot on rye in 1927–8. Livestock may be poisoned by eating ergoted hay or when fed with affected rye screenings, but it is difficult to substantiate the claim sometimes made that Ergot causes abortion in cows and ewes in this country, especially in view of the widespread occurrence of other forms of abortion in domestic animals.

Control measures for Ergot have not yet proved to be necessary in Britain. With rye much of it is removed from contaminated samples in the milling process. It is always advisable, however, to use clean seed or seed

that has been freed from ergot by floating it in a saturated salt solution. A method that has been found suitable for barley is to pre-soak the grain for about three hours in water and then float off the ergots in a salt solution containing about 40 lb common salt in 25 gallons of water. Deep ploughing and rotation of crops are effective remedies because ergots buried 10 in. deep do not germinate and they appear to die after a year. It is uncertain to what extent Ergot on grasses is a menace to cereal crops; a form on perennial and Italian ryegrass does not attack rye or other cereals but one on *Alopecurus* has been found to infect wheat.

BLACK MOULD

Blackening of wheat ears is a cause of much concern and often alarm among farmers, partly because it is so conspicuous, especially in wet seasons, and partly because the affected ears are generally empty or only poorly filled. If wet spells occur when the ears are ripening a black mould develops on the heads, and even sound, well-filled ears may become discoloured. Ears that for one reason or another are weak, poorly filled, or blind, become literally covered with the mould. More than one "sooty mould" fungus may produce this effect, but by far the commonest one is *Cladosporium herbarum* Fr. which grows on all kinds of dead and decaying vegetable matter. It is not an active parasite, however, and the sudden development of Black Mould on the ears need not give rise to alarm, for if the crop is otherwise healthy the *Cladosporium* itself will do little or no harm and will have no adverse effect on the ripening or germination of the grain; it is not a cause of thinning-out or deaf ears. Indeed, ear blackening should be regarded, not as a definite disease, but as a sign that the crop has been affected, probably for a considerable time, by some entirely different trouble which has led to the production of defective ears. These defective ears then become colonized by *Cladosporium* or other secondary fungi. In other words, Black Mould is a result and not a cause of disease. The primary cause may be, and very often is, an attack of Take-all (p. 17), Brown Foot Rot (p. 20) or one of the other foot and root rot diseases, or it may be malnutrition, such as a deficiency of potash, which leads to delayed ripening, deaf ears and shrivelled grain. Again, in some seasons Mildew (p. 25) spreads from the foliage to the heads, or the ears may become badly attacked by Glume Blotch (p. 29). When this happens *Cladosporium* or some other "sooty mould" fungus develops secondarily on the affected ears and gives rise to the typical black mould appearance.

BLACK POINT

Black Point, or Kernel Smudge as it has been called in Canada, is found on wheat, rye and barley wherever cereals are grown. It is essentially a disease of the grain, and can be readily recognized by a brown, dark-brown or almost black discoloration and local shrivelling at the embryo end, and occasionally elsewhere on the grain. The disease varies in intensity from season to season. It is commonest in the larger, plumper grains, and in countries where they are cultivated the durum wheats are particularly susceptible to it.

The presence of discoloured grains in a threshed crop naturally lowers its market value, if only because affected grain is undesirable in stocks intended for use as milling wheat, malting barley or as seed. The significance

of the disease may, however, extend beyond this, because germination and subsequent growth are sometimes adversely affected by it. Black Point is a fungus disease, which can be caused by a number of different parasites, and the extent to which it affects germination and growth depends on the particular fungus concerned. Usually it is a species of *Alternaria*[1], which is more or less harmless, or a species of *Helminthosporium*, which is apt to impair germination. In North America, for example, where *Helminthosporium*, and particularly *H. sativum*, is a common cause of Black Point, the sowing of affected grain may lead to seedling blight and foot rot (p. 22), but in Britain, where the fungus is almost always a species of *Alternaria*, germination is not impaired and the disease is of no importance apart from the undesirability of black-ended grains in otherwise clean seed. Infection by the fungi takes place at any time after the florets open, but most of it probably occurs while the grain is in the 'milk' stage or later. The source of infection appears to be air-borne spores, or spores carried over from the leaves or glumes.

TWIST

Twist is a fungus disease caused by *Dilophospora alopecuri* (Fr.) Fr.[2] Though once widely distributed in Britain it is now very rare. It has been reported from time to time since 1862, usually on wheat, twice on oats, and occasionally on grasses, including *Alopecurus* and *Holcus*; in one or two instances wheat crops have been ruined by it. On the Continent the disease has at times caused severe damage to rye and oats as well as wheat. Formerly it was thought that Twist developed only on plants already infested with the eelworm that causes Ear Cockle in wheat (*Anguina tritici* (Steinbuch) Filipjev). While it is true that the eelworm may help to spread the spores of the *Dilophospora*, however, there is no obligatory relation between the two troubles, and each may occur independently of the other.

Twist does not usually become conspicuous until after heading, but it may be seen on comparatively young plants, the leaves of which are often undulated or spirally rolled, and bear pale spots that later darken as the fungus produces its spore cases (pycnidia) on them. The disease becomes clearly recognizable when the ears emerge, for they are either stunted and partially killed or are badly deformed. Under dry conditions the ear emerges dry and withered, with the fungus mainly internal. Under humid conditions the fungus envelops the ear, while it is still within the sheath, with a thick, wad-like, white mycelium that binds it to the sheath and either prevents its emergence altogether or so hinders its upward movement that, as growth proceeds, the flowering stalk and ear become twisted and curved into the most bizarre shapes. After exposure to the air for a few days the white mass of mycelium shrivels and blackens, and ultimately the freed ear resembles a charred mass (Fig. 14), in which the fungus forms innumerable spore cases (pycnidia). Twist may be carried with the seed, and as the fungus is present inside the seed coat as well as on the surface, external disinfection of the seed with a fungicidal dust is unlikely to give more than a partial control. Seed

[1] *Alternaria tenuis* Auct., *A. fagicola* Cavara, *Helminthosporium sativum* Pamm., King & Bakke, and *H. teres* Sacc., are the chief species involved. *Cladosporium herbarum* Fr. is frequently associated but is probably only secondary. The bacterial disease caused by *Pseudomonas atrofaciens* McCull. Stapp, sometimes included under Black Point, is regarded here as distinct (p. 32).

[2] Contrary to the opinion sometimes held, *D. alopecuri* is not related in any way to the fungus *Mastigosporium album* Riess, which causes a leaf disease of certain grasses.

should therefore never be saved from the few crops that become infected with the disease.

SEPTORIA DISEASES

Among the minor fungus diseases of cereals there is a group caused by a number of closely related species of *Septoria*, which produce bleached or discoloured spots or blotches of varying sizes and shapes on the leaves and leaf sheaths of wheat, oats, barley, and rye. These diseases have much in common. They closely resemble one another in external appearance and all occur on the foliage and some also attack the ears and stems. The spore cases (pycnidia) of the fungi that cause them appear as numerous minute, black dots on the bleached or discoloured spots. Under the microscope, however, it is possible to distinguish these fungi from one another by small morphological differences, and each one is virtually restricted to its own particular host. These species of *Septoria* live over winter in the field on bits of straw and leaf remains, from which they pass to the young cereal crops when growth is resumed in spring. They spread freely in wet weather, but are quickly checked in periods of drought. Brief notes on the individual diseases are given below. Most of them occur in Britain but they are of little or no economic importance and special measures for controlling them are unnecessary.

Glume Blotch

Glume Blotch of wheat, caused by *Septoria nodorum* Berk.,[1] is found wherever wheat is grown. It occurs in all parts of Britain, becoming prominent on the ears in July and August, especially in wet seasons. Irregular, chocolate-brown spots or blotches develop on the glumes, beginning at the tips, and later the ears may become blackened as a result of the secondary development of Black Mould (p. 27). The leaves also show yellowish areas, which soon become differentiated into spots with a pale centre and brown margin, and may spread and coalesce until the leaves are killed. In wet weather the fungus also attacks the stems and leaf sheaths, causing brown areas particularly around the upper joints or nodes. *S. nodorum* is able to attack rye foliage but not oats or barley. When severe, Glume Blotch is apt to reduce yield and quality of the seed, but the disease is rarely important in Britain and the grain within the glumes usually remains plump and undamaged. It has been shown that the fungus is commonly seedborne and that organo-mercury seed treatment will give good control.

Leaf Spot

Leaf Spot of wheat is caused by *Septoria tritici* Desm. It can be found most years in the southern half of England and Wales in April, but does no noticeable harm. Rye may also be affected, but not oats or barley. The foliage of affected plants shows light coloured, rather indefinite spots, pimpled over with the dark spore cases of the fungus, thus giving the spots a speckled appearance. Hence the name Speckled Leaf Blotch, by which the disease is known in North America, where it sometimes kills the young seedlings and causes premature death of the leaves.

Speckled Blotch

Speckled Blotch of oats has been recorded in North America, Europe, Australia and South Africa. It occurs widely in Britain and is sometimes

[1] The perfect state *Leptosphaeria nodorum* Müller has not been found in Britain.

damaging in Scotland, and in northern districts of England and Wales. The disease is caused by the fungus *Septoria avenae* Frank.[1] Round or elliptical, yellow to brown spots, up to ⅛ in. across, and speckled with numerous black dots, are found on the leaves and leaf sheaths. The similar Leaf Spot of barley (*Septoria passerinii* Sacc.) has been reported occasionally in Britain and the one on rye (*S. secalis* Prill. & Delacr.) has only been found in Scotland. *Selenophonia donacis* (Passer.) Sprague & A. G. Johnson, the cause of Halo Spot of cocksfoot, timothy and other grasses in Britain, has been found on barley in Eire, in Scotland, and on a few occasions in England.

DOWNY MILDEW

This is another disease that has not yet been seen in Britain. It is caused by the fungus, *Sclerospora macrospora* Sacc., and has been found attacking wheat, barley, oats or rye in various parts of North America, Europe (especially Italy), Australia and Japan. It occurs also on maize, rice, and wild grasses. The disease becomes troublesome only in moist, low-lying, poorly-drained or waterlogged fields or parts of fields, though scattered slight attacks have been observed from time to time in well-drained fields where flooding is unlikely to have occurred.

Some affected plants produce numerous tillers which turn brown and wither when they are only a few inches high; and such plants usually die early. Others struggle on but remain stunted and the leaves, instead of being dark green and flexible, show yellow stripes or are almost completely yellow. They also become fleshy, twisted or curled, and stand out in stiff unnatural positions. Slightly affected plants develop more or less normally, apart from partial yellowing, thickening, and twisting of the foliage. Most diseased plants fail to produce heads, and those that are formed are usually distorted, deformed and barren. An apparently reliable method of diagnosing the disease is to hold an affected leaf up to the light and examine it with a hand lens. If Downy Mildew is present, numerous clear dots can be seen in rows along the veins or even in the veins themselves. These dots indicate the presence of the resting spores (oospores[2]) of the fungus, which reach the soil when the leaves decay and remain alive there to infect subsequent susceptible crops. No satisfactory method of controlling the disease is known.

SNOW ROT

In certain parts of Europe, notably northern Germany and Scandinavia, and in the United States of America and Japan, considerable rotting and yellowing is frequently revealed in winter crops of wheat, barley and rye when the snow melts in spring. The disease has been recognized on a few occasions in Britain; it has been recorded on wheat, barley and oats. In America, where the disease has been called snow scald, large patches of the ground may be covered with the greyish-white, collapsed and matted foliage of dead plants. In Europe, where barley is the chief crop attacked, the effect seems to be less drastic. Diseased seedlings are backward in growth; the outer leaves, and, later the inner ones, gradually turn yellow and brown

[1] The perfect state of this fungus is *Leptosphaeria avenaria* Weber.

[2] The conidial state has been seen only in Japan, where the fungus has been transferred to *Phytophthora* as *P. macrospora* (Sacc.) Ito & Tanaka.

from the tips downwards, and many plants are killed outright. Others manage to survive, and as temperatures rise, they slowly grow away from the disease and may even form a few weak and badly filled heads. The rot is caused by fungus usually referred to as *Typhula incarnata* Lasch, and it can be recognized most easily by the presence on and in the roots, crown, leaf sheaths and stem base of numerous, reddish-brown, round or irregular bodies about the size of clover seed. These are the resting bodies or sclerotia of the fungus; and sooner or later they reach the soil. Here they remain dormant until the following spring, or perhaps longer, and then germinate to give thread-like, spore-bearing organs. The spores formed on the thread-like bodies are blown about by wind and serve to infect young cereal crops in the neighbourhood. Crop rotation, late sowing, shallow sowing, and adequate manuring are among the measures recommended for avoiding the disease.

CEPHALOSPORIUM LEAF STRIPE

Although recorded from Japan in 1930, it is only since 1955 that this disease caused by the fungus *Cephalosporium gramineum* Nisikado & Itaka has been recognized as economically important elsewhere. It is widespread and in some seasons serious in the cool humid regions in the Washington and New York States of U.S.A., and has recently been found in small amounts in Scotland and in England. Wheat is most often affected but barley, oats and rye are also attacked: it has been found occurring naturally on a number of grasses and has been artificially inoculated into a wide range of grasses.

The fungus is soil-borne; it invades the plants through the roots and spreads up the stem and into the vascular tissues of the leaves. It has been found to produce spores in the vessels and this may well account for its very rapid spread within the plant. Leaves on affected plants show striking yellow stripes and this striping is continued down the leaf sheath on which there is frequently also a brown necrotic streak down the main vein. This striping is most conspicuous in wheat and slightly less so on oats and barley. Older leaves become completely yellowed. Invaded vascular tissue is blackened and this can be seen readily in the nodes of affected stems.

It has been shown that the disease can be seed-borne but experience suggests that this is unimportant except for the introduction of the fungus into a new area. Survival of the fungus on crop debris is very important. Adequate rotation and the use of resistant varieties are the recommended control measures in those areas where the disease is of significance.

Bacterial Diseases

BLACK CHAFF

The name Black Chaff covers more than one disease, but is used here in a restricted sense to signify a bacterial disease caused by *Xanthomonas translucens* (Jones *et al.*) Dowson em. Hagborg[1]. Symptoms closely resembling those produced by the bacterium may develop on rust resistant varieties of wheat as a reaction to infection by Black Rust (p. 3) or may be induced under conditions of high temperature and humidity (p. 39).

Black Chaff occurs in North America and various parts of Europe, Africa, and Australia, but has not yet been recognized in Britain, though it is not excluded that Brown Neck (p. 38) may belong here. Wheat, oats, barley and rye, as well as certain grasses, may be attacked by different races of the bacterium, some of which are restricted to a particular host. The disease affects all parts of the plant, including the seed, but is most conspicuous on the glumes and the upper part of the stems. It may begin in the seedling stage, but is often not noticed until the ears begin to emerge. Numerous, small, water-soaked areas appear on the foliage and these gradually unite and spread along the leaves until they assume the form of long or short, yellowish or brownish, translucent stripes. Conspicuous brown or black stripes also develop on the stems, especially just below the ears and around the joints, and longitudinal, more or less sunken, dark stripes or spots are formed on the glumes. In moist weather the bacteria often ooze from the spots or stripes as little beads or drops, which harden into yellowish resinous granules as they dry. These granules soon soften again when more rain falls and it is probable that rain and wind provide the chief means by which the disease is spread in the field.

The bacteria reach the surface of the grain from the glumes and may eventually penetrate the seed, especially at the base, which becomes shrunken and honeycombed with pockets of bacteria. When the disease appears early (as it may do if infected grain is sown) and becomes severe, the affected leaves turn yellow and die, and the heads remain dwarfed and are partly or wholly barren. Warm, wet seasons favour epidemic attacks, high humidity apparently being more important than high temperature.

Little attention has been given to the control of Black Chaff. Frequent application of sulphur dust will keep it in check, but this method is impractical on a large scale, and the wisest precaution is to avoid using seed from infected crops.

BASAL GLUME ROT

Basal Glume Rot of wheat, though sometimes regarded as a form of Black Point (p. 27) is really quite distinct from it and is caused by a bacterium, *Pseudomonas atrofaciens* (McCull.) Stapp. It has been reported on wheat and barley in North America, and on wheat in Australia and South Africa, but

[1] This disease was formerly attributed to a number of different bacteria, including *Bacterium translucens* var. *undulosum* E. F. Sm. *et al.*, and *B. translucens secalis* Reddy *et al.*, which were distinguished mainly by their ability or inability to infect wheat, barley, oats and rye. They were, in effect, different physiologic races of the one species *X. translucens* and are best regarded as such.

is unknown in Britain. The ear is the part chiefly attacked, and the most noticeable symptom is a brown or black discoloration of the lower part and sometimes of the whole of the glumes. The embryo end of the often poorly-developed grain sometimes has a charred appearance and occasionally small, light brown spots are formed on the leaves. Bacteria are present in abundance in the discoloured tissues.

HALO BLIGHT

Halo Blight of oats was first described from the United States of America and it has also been reported from Europe, New Zealand and Eire. It is widely distributed in Scotland, and has been recorded occasionally from Wales and Northern England. The disease is caused by *Pseudomonas coronafaciens* (Elliott) Stapp, and care is needed to distinguish it from the non-parasitic Grey Leaf (p. 36) and from Leaf Spot (p. 13). Halo Blight begins as spots on the seedling leaves and later spreads to older leaves, leaf sheaths, and glumes, though most prominent on the earlier-formed leaves. At first, each spot consists of an oval, pale green and halo-like area, $\frac{1}{4}$–$\frac{3}{4}$ in. long, with a small brown, dead centre. Later, the spot may become more irregular as several short, pale green "tongues" spread out from it along the leaf. More and more of the central tissues become grey-brown or even reddish-brown, but there is always an outer pale green or yellowish halo, which is often still visible after the leaf has withered. Where the spot is marginal, the leaves may become locally kinked or constricted, and the presence of several spots on the same leaf generally leads to shrivelling and drying up of the leaf tips and margins, or even to general yellowing and complete collapse of the upper part of the blade. The panicles of severely affected plants are usually badly blasted, but the cold wet weather that greatly favours the spread of the disease may sometimes be partly responsible.

Halo Blight is carried with the seed and the primary lesions of the disease appear on the first seedling leaves. The bacteria are then carried to other leaves by rain and wind. Seed treatment with organo-mercury dusts does not control the disease. Steeping or sprinkling the grain with formaldehyde as for wheat Bunt (p. 7) is partially effective; under experimental conditions warm water treatment of the seed at 57°C (134.5°F) for 10 minutes has given complete control and very promising results have been obtained with streptomycin.

BACTERIAL STRIPE BLIGHT

A Bacterial Stripe Blight of oats has been reported from North America, Australia and Russia. It is distinct from Halo Blight and is caused by a different bacterium, named *Pseudomonas striafaciens* (Elliott) Stapp. The symptoms first appear on the leaves as numerous, sunken, water-soaked dots which unite to form blotches with narrow yellowish margins, or long water-soaked stripes that later become rusty brown. Under moist conditions a bacterial exudate stands out in drops along the stripe. The leaf sheaths, pedicels and glumes may also be attacked. Stripe Blight can readily be distinguished from Halo Blight by the long, water-soaked stripes, the absence of a halo and the presence of a bacterial exudate.

Virus Diseases

The only virus disease of cereals that is known to be of economic importance in England and Wales is Barley Yellow Dwarf. This disease attacks wheat and oats as well as barley, and in some seasons can cause quite serious losses.

The leaf tips of young, infected barley plants turn golden yellow, the yellowing spreads down the leaf and the plant is stunted. Tillers are usually less affected and may produce a light crop. Plants that become infected at a later stage of development are less stunted but the ears are often "blasted" and the crop is much reduced. The effect on wheat is similar, but the yellowing of the leaves is much less pronounced. In oats the yellow areas quickly change to red or purple. The disease is usually not difficult to recognize in young barley or oats but in older plants or in wheat it is readily confused with the effects of nitrogen deficiency or other adverse conditions.

The yellow dwarf virus is spread from plant to plant by aphids; and several strains of the virus occur, some of which are transmitted by one of the species of aphids found on cereals and some by others. The strains most commonly found in England are transmitted by *Rhopalosiphum padi* (the bird-cherry aphid). The virus can infect many grasses and these act as reservoirs from which infection is spread to cereals.

Usually only individual cereal plants or small patches round the edges of fields become infected. After mild winters when large numbers of aphids survive, (and especially if the mild winter is followed by a dry spring which encourages aphids on grass to migrate to cereals), whole fields, particularly of winter-sown cereals, may become infected. Such fields produce little or no crop and may have to be ploughed in. There is no cure for the disease and at present no satisfactory method of control is known.

Other important virus diseases of cereals, transmitted through the soil, through seed, by mites or by leaf hoppers occur outside the U.K. Wheat Striate Mosaic (transmitted by leaf hoppers) Ryegrass Mosaic (mite transmitted) and Barley Stripe Mosaic (seed-transmitted) have been detected in England on wheat, oats and barley respectively. Each of these diseases is potentially dangerous but, although there is little information about their prevalence, it appears that they are of minor importance at present.

Non-Parasitic Diseases

FROST INJURY

It is not always easy to distinguish frost injury in cereals from the effect of low temperatures in the absence of frost, drying winds and other climatic or pathological factors. As a rule, low temperatures without frost induce leaf colouring—pink or red in oats and rye, brownish in wheat, and yellowish in barley—especially at the tips, while spots or "frost rings" lower down the leaves, leaf tearing, or curling and rolling of the foliage.

Late spring frosts sometimes lead to partial or complete "deafness" or blindness of the ears of cereal crops. In 1944, for example, there were severe May frosts in England which had an indirect as well as a direct effect on the subsequent development of the ears. Many wheat crops in eastern and southern districts showed a varying amount of "ear tipping". The tips and upper parts of the ears were white, shrivelled and empty, and this condition was attributed to the direct effect of frost on the flower parts at a time when the ear was just emerging from the leaf sheath. Poorly grown crops, short in the straw, were the most damaged and varieties that showed early emergence generally escaped. A few barley and rye fields were also affected in the same manner. The injury was not always restricted to the upper parts of the ears; indeed, it was sometimes only the middle or lower spikelets that were bleached and empty. In general, the ears appear to be sensitive to low temperatures only for a short period during and immediately after emergence.

In August an indirect effect of the late frosts on the ears was observed in south-eastern districts, where shrivelled grain and partially filled ears were a feature of many wheat crops. This condition was not associated, as it usually is, with foot rotting fungi or other parasitic diseases, but with frost damage to the lower part of the straw. Similar damage had been noticed towards the end of May in crops that exhibited much leaf tip browning and a certain amount of lodging. It took the form of browning, or bleaching and shrivelling of the lowest two internodes of the stem, and a dark brown discoloration of the lower nodes, visible only when the lower leaf sheaths were removed.

In countries with a continental climate the effects of early autumn frosts on the immature grain may result in the production of "glassy" or "frosted" grain, the seed value of which is very low. Glassy grain is hard, almost transparent, and grey or reddish when cut through, while frosted grain has a characteristic blistered appearance.

BLAST OF OATS

The term "blasted oats" is commonly used to describe any oat crop that contains a substantial number of sterile spikelets, and as such it describes a symptom and not a disease, for there are many things that may lead to barren heads, including attack by parasitic diseases such as Leaf Spot (p. 13), foot rots, or a bad attack of Crown Rust (p. 5), as well as frost. In a narrower sense Blast of oats implies failure to produce seed in an otherwise normal

plant; some spikelets are empty and others full, and the loss in yield is directly related to the amount of blasting. The severity of this form of Blast is affected largely by environmental conditions during the period from the initiation of the spikelets until just before the panicle emerges. A reduced water supply at this stage promotes the trouble, as also does the withholding of mineral nutrients and poor or excessive light. As a rule there is more blasting in late sown than in early sown crops, and late tillers are apt to show more of it than the earlier ones.

MANGANESE DEFICIENCY DISEASE (GREY LEAF)

For many years a serious disease of oats has been known to occur on certain types of alkaline soils in Britain, north-west Europe, and Australia, and in more recent years it has been recognized in North America, Japan and elsewhere. It has been called, among other names, Grey Leaf, Grey Speck and Dry Leaf, none of which is very suitable. Many crops, including other cereals, potatoes, and sugar beet become affected in the same soils, and the symptoms differ markedly according to the host. Consequently, as the disease is now known to be caused by a deficiency of available manganese in the soil it is preferable and more convenient to use the term Manganese Deficiency disease for it.

The soils on which the symptoms of manganese deficiency develop are invariably alkaline and often have a high content of organic matter. In Britain this deficiency is prevalent in Yorkshire and the skirt soils of the fenlands, and sporadic elsewhere on poorly drained soils over chalk or limestone, reclaimed heath soils, wet alluvial silts and clays derived from calcareous soils and many black soils that have been generously limed. It is very apt to occur on sewage farms where the sewage has been heavily limed before application to the soil.

Although oats is the most susceptible of the cereals, wheat, barley and, to a less extent, rye may also be affected. In oats the symptoms appear on the foliage when the plants are 4–8 in. high. Light green spots or short streaks that soon become grey or buff-coloured, develop on the basal portions of the leaves, particularly at the margins. The spots enlarge, coalesce, and extend across the leaf blade or form long streaks between the veins (Fig. 17). When this happens the leaf bends over sharply in the middle, the lower half soon dies while the upper half may remain green and hang limply for a time. Ultimately, however, the whole leaf turns brown and withers. The root system is often poorly developed, and badly affected plants, after being reduced to a small green shoot lying in the centre of shrivelled, brown leaves, often die. If the disease is not too severe, natural recovery may take place after midsummer, particularly in wet seasons; the plant grows away from the trouble and heads may be formed, though they bear few grains and may be quite blind. Some varieties are more susceptible than others; Scotch potato oats and Radnorshire Sprig, for example, are very resistant, while Orion, Star, Victory, Black Tartarian and Golden Rain II are moderately or very susceptible.

On wheat and barley the leaves may show nothing more than faint chlorotic streaking and yellowing. On severely affected wheat elongated white specks or spots are sometimes found between the veins, or the symptoms may more closely resemble those on oats, while numerous, small,

brown or grey spots or streaks occur on the leaves of badly affected barley. Whitish spots develop on rye leaves, some of which bend over in the manner typical for oats.

The effect of manganese deficiency is accentuated by drought conditions, and the disease is always more severe when spring weather is warm and dry. It can be avoided by treatment with manganese sulphate. It is sometimes sufficient to give a surface dressing of about 50 lb per acre to the soil in spring, but this is by no means effective on all soils. Spraying methods are better, for they use less material and can usually be relied on to give satisfactory results. Spraying with a 1 per cent solution of manganese sulphate (10–20 lb per acre), to which a wetter has been added, is therefore advised as soon as the disease is noticed or—where the disease is known to be troublesome—when the plants are about 4 in. high. The response is a quick one and can frequently be seen about ten days later. Manganese chloride may also be used, but the residual effect of both salts is slight; and a more lasting effect can sometimes be obtained with fairly heavy soil dressings of sulphur, which help to acidify the soil and so counteract the adverse effect of alkalinity.

OTHER DEFICIENCY DISEASES

Nitrogen

The chief signs of nitrogen starvation are stunted and spindly shoots, sparse foliage of a yellow-green to yellow colour, and poor tillering. The stems may show reddish or purplish tints in oats and barley, and the heads and grains are small. The deficiency can usually be made good by top dressing with a nitrogenous fertilizer in spring, but care should be taken to regulate the amount according to seasonal conditions. Larger quantities are usually needed after a wet winter when more available nitrogen will have been removed in the drainage water; moreover, when the soil is cold and wet in spring, bacterial activity is apt to be slow in starting.

In the United States of America an abnormal condition of the harvested wheat grain, known as Yellow Berry, is believed to be caused primarily by nitrogen deficiency. Instead of being hard and translucent the grain is partly or wholly light yellow, opaque, soft and starchy. Some grains bear only one or more yellow spots, and when these are cut across, the spots appear in section as white, mealy or starchy places embedded in the normal, horny, translucent tissues. Yellow Berry is a sign of low protein wheat and of nutritional disturbances resulting mainly from deficiency of nitrogen. It is found in grain from soils with a high potash-phosphate status, and can be avoided by restoring a proper nitrogen-phosphate-potash balance by such methods as including legumes in the rotation, the use of green manures, summer fallowing, and the application of nitrogenous fertilizers.

Phosphorus

Phosphorus deficiency is most likely to occur in the high rainfall districts of the west and north, on clay soils, chalk downlands, and in fen districts. It may be suspected where slow growth and poor tillering is accompanied by a dark, bluish-green colour in the young leaves and stems. Purple tints develop later and may be prominent in the heads. With cereal crops it is an advantage if phosphates are applied by a combined seed and fertilizer drill.

Potassium

Potassium deficiency is found chiefly on the lighter sandy and chalk soils and is greatly accentuated when the soil is dry. Affected plants are weak and stunted, usually with many tillers and few flowering stems. As in most cultivated crops suffering from potassium deficiency, the leaves show scorching of the margins and tips. In barley, which is particularly susceptible, this may be accompanied by small, purplish-brown spots. The heads are few and poorly developed, and the grain is often shrivelled and immature.

Magnesium

Magnesium deficiency has proved troublesome in certain parts of Holland, especially in oats, but is rare in this country. It is most prevalent on light, acid soils and in wet seasons. Affected plants are dwarfed, stiff, and yellowish-green. The leaf blades, particularly of wheat and oats, exhibit a "tiger-skin" striping, and in rye they often fail to unfold. The trouble, which is accentuated when there is also a deficiency of calcium in the soil, can usually be corrected by appropriate soil treatment. Soluble magnesium sulphate materials, such as Epsom salts, give a quick response, and an occasional dressing with magnesium limestone, though slower-acting will last and be effective for several years.

Copper

Copper deficiency diseases are prominent on newly cultivated or reclaimed moorland and on heath soils in Holland, Denmark and parts of Germany, where they are known under various names, such as Reclamation Disease and Yellow Tip. There are also extensive tracts of copper deficient soils in South and West Australia. This deficiency has now been detected in soils in East Anglia. All the cereals except rye are very susceptible, but as oats and barley are grown most frequently on the types of soil in question, they are the ones that suffer most. Affected plants tiller freely but remain stunted and bushy. The foliage is green below, but shows a tendency to wilt, while the younger leaves which may fail to unfold, have pale green margins and white, shrivelled tips. Many of the heads are blind or deaf, and yield is appreciably reduced. The condition can generally be corrected by surface dressings of finely crystalline copper sulphate (bluestone), used at the rate of 30–50 lb or more per acre, or of other copper compounds. Copper slag is also effective but greater quantities are needed.

Cereal crops rarely, if ever, show signs of *iron* or *boron* deficiency. *Zinc* deficiency is said to be responsible for poor yields of oats on some light soils in Australia, but is not known in Britain. On the other hand, *zinc toxicity* has been observed a few times in soils containing considerable amounts of zinc. Affected wheat plants become bright yellow, cease growing and ultimately die.

BROWN NECK OF WHEAT

Brown Neck has been known for a long time in this country and in some years is very common, but little attention has been given to it. Just before the ears and straw begin to lose their green colour, a deep brown or blackish stain, about an inch long, appears immediately below the ear (Fig. 18). Smaller patches may occur on the straw several inches below the ear, and

occasionally the chaff is also discoloured. The stain is due to the disorganization of the superficial cells that contain the green colouring matter (chlorophyll). Globules of what appear to be oil are formed in these cells, which become dark brown and die. Brown Neck appears to be merely a surface blemish that has no adverse effect on the ear or the straw. The cause of it is unknown. The trouble has been regarded as identical with Black Chaff (p. 32) but there is as yet no satisfactory evidence in support of this. It is perhaps more nearly related to a form of melanism (blackening) recently distinguished in Canada and attributed to the action of high temperatures in association with high humidity.

LOOSE EAR OF WHEAT

Loose Ear of wheat is more an oddity than a disease, which attracts notice from time to time. Isolated ears in a crop become bleached before maturity, and stand out conspicuously as "whiteheads". They bear no relation to the Whiteheads caused by foot-rotting fungi, however, and when examined, the stalk inside the sheathing leaves is found to be severed several inches below the ear, which can be pulled out without resistance. The ear and severed part of the stalk is bleached, while the stalk below the breakage remains green. It is not known how or when the fracture occurs. On several occasions these symptoms have been attributed to grazing by cattle that had strayed into the crop after the ears had emerged.

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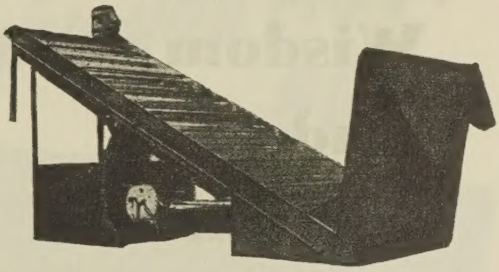

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